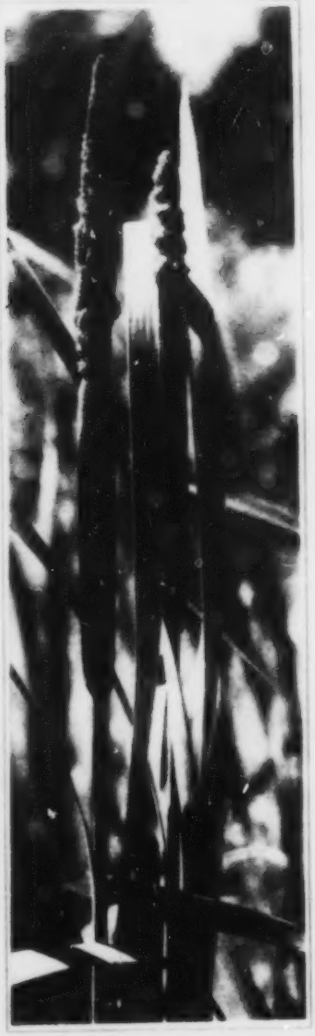
EVALUATION OF WETLANDS FOR NUTRIENT REMOVAL FROM COAL MINE WASTEWATER

A THREE YEAR STUDY

MARCH 1992



Prepared for:

Conservation and Protection
Environmental Protection Mining, Mineral and Metallurgical
Process Division

Funded by:

This work was supported in part by the
Federal Panel on Energy R & D (PERD)
Office of Energy Research and Development (OERD)
Task-2, Oil Sands Heavy Oil and Coal

Norecol
Environmental
Consultants Ltd

92-07066/

EVALUATION OF WETLANDS FOR NUTRIENT REMOVAL FROM COAL MINE WASTEWATER:

A THREE YEAR STUDY

Prepared for:

Environment Canada
Mining, Mineral and Metallurgical
Process Division
351 St. Joseph Boulevard
Hull, Quebec
K1A 1C8

Prepared by:

Norecol Environmental Consultants Ltd.
Suite 700, 1090 West Pender Street
Vancouver, British Columbia
V6E 2N7

March 1992

File: 1-051-03.06

EXECUTIVE SUMMARY

Nitrate enrichment of drainage waters from coal and metal mines is a concern because of potential impacts on receiving water quality. Residues of the nitrogen-based explosives commonly used at mines may leach to surface waters where they can stimulate algal growth, sometimes affecting fish habitat. As a result, treatment of mine waters is becoming a priority, and there is a need to evaluate cost-effective methods to control nitrate release to the environment.

One promising treatment option is the use of natural or artificial wetlands. Therefore, a three-year pilot study of wetland treatment for nitrate-enriched coal mine wastewater was conducted at the Quinsam Coal Ltd. mine near Campbell River, British Columbia. The overall objective of the pilot study was to design and test a field scale wetland for nitrogen (N) and phosphorus (P) removal from wastewaters generated at an operating coal mine. Removal of metals was tested incidentally.

This report documents the Year 3 results and describes the overall results and conclusions of the study. The report also reviews recent literature on artificial wetlands and macrophyte ecology related to wastewater treatment. It provides preliminary wetland design criteria based on the results of the pilot study and information from current literature. The results of Years 1 and 2 are detailed separately in Norecol (1989) and Norecol (1990), respectively.

In 1988, an 800 m^2 experimental wetland was constructed within a natural wetland at the Quinsam Coal mine. Existing woody vegetation was cleared to favour the growth of sedge (*Carex* sp.), which is more desirable for water treatment. Cattail (*Typha* sp.) was transplanted into the experimental enclosure to increase the diversity of marsh species. Water for the experimental wetland was piped from the mine's main settling pond. The water depth in the wetland averaged 0.1 m and the retention time (including rainfall) ranged from 1.7 to 3.4 days. The settling pond effluent was supplemented with potassium nitrate (KNO_3) fertilizer to produce a NO_3-N influent to the wetland of 10 mg/L in Year 1 and >20 mg/L (maximum 120 mg/L) in Years 2 and 3.

Surface and groundwater, soil, and vegetation samples were collected for chemical analyses. Water samples were collected at the inlet, midpoint, and outlet of the experimental wetland. Vegetation samples included above-ground and below-ground tissues of cattail, sedge, and sweetgale.

Mass loading and discharge of nitrogen and phosphorus were estimated from the concentration and flow data for the inlet and outlet. To the extent possible, nutrient removal was apportioned among microbial, vegetation, exfiltration, and other pathways (microbial and below-ground plant biomass components were estimated by subtraction only).

Nitrogen was removed very effectively by the wetland in all three years of the study. On an annual basis, N removal efficiency increased from 87% in Year 1 to 98% in Year 3. There was some seasonal variability, but N removal efficiencies were above 80% even in the winter months, while summer efficiencies approached 100%. Although total N removal efficiency was always high, export of minor amounts of ammonia (NH_3) and nitrite (NO_2) occurred during the winter.

The highest proportion of total N mass (84%) was removed by the combined pathways of denitrification and production of below-ground biomass and macrofauna. It is estimated that denitrification alone accounted for at least 77% of the N mass removed. Production of above-ground plant tissue accounted for 8.1% and exfiltration accounted for 5.9% of the remaining N removal.

Phosphorus was also removed by the wetland, but P removal was much less efficient than N removal. On an annual basis, P removal efficiency was 40% in Year 1, 48% in Year 2, and 30% in Year 3. The decrease in P removal efficiency in Year 3 is apparently related to the maturity of the wetland plant community and suggests lower P storage in the maturing vegetation and microbiota. Above-ground vegetation and exfiltration accounted for approximately 5.5% and 1%, respectively, of the total P removed. Below-ground pathways (assimilation and storage in plant roots and rhizomes and in soil microorganisms, and possibly adsorption or complexation in the wetland peat) accounted for 93.5% of the P removal.

The seasonal variability in P removal efficiency was much higher than the variability in N removal efficiency. Maximum summer P removal efficiencies were between 40% and 50%, but net export of P occurred during some spring months.

In general, the wetland tended to remove metals, although considerable variability was observed among metals, seasons, and years. All metals levels encountered were considered to represent natural background conditions without significant influences from mining activities. Dissolved aluminum and iron were exported from the wetland during the growing season but removed during the remainder of the year. Potassium, manganese and zinc (which were present almost entirely as dissolved metals) tended to be removed in the wetland, although some export of particulate zinc occurred during spring and fall rains. Copper was removed in the wetland during Year 3, but particulate copper tended to be exported during the growing season in Years 1 and 2.

The study has confirmed empirical design guidelines adapted from wetlands treatment experiences with municipal sewage. The nitrogen removal results obtained in this study with a low-level nitrogen wastewater are considerably better than those commonly obtained with high-nitrogen wastewaters such as domestic sewage. The results lead to the following recommendations: (1) Wetland design for N removal should be based on mass loadings expected during the growing season, and on hydraulics, and (2) Based on peak growing season flows and the high nitrogen removal efficiency observed in the Quinsam wetland, a minimum hydraulic retention time of three days should be sufficient to achieve satisfactory (>80%) nitrogen removal. The data produced by this study can eventually be combined with data generated by future wetland studies to produce quantitative design criteria for water treatment wetlands.

PROJET QUINSAM SUR LES TERRAINS MARÉCAGEUX

RAPPORT FINAL

SOMMAIRE

L'enrichissement des eaux de drainage par les nitrates à partir des mines de charbon et de métaux est préoccupant en raison des impacts potentiels sur la qualité des eaux touchées. Les résidus des explosifs à base d'azote que l'on utilise couramment dans les mines peuvent filtrer vers les eaux de surface où ils peuvent stimuler la croissance des algues et avoir parfois un effet sur l'habitat des poissons. En conséquence, il devient prioritaire de traiter les eaux des mines et il est nécessaire d'évaluer des méthodes rentables pour freiner le rejet des nitrates dans l'environnement.

Une voie prometteuse pour ce traitement consiste à utiliser des marécages naturels ou artificiels. Ainsi, à la mine Quinsam Coal Ltd près de Campbell River (Colombie-Britannique), on a mené une étude-pilote de trois ans sur le traitement en terrain marécageux des eaux usées d'une mine de charbon. L'objectif d'ensemble de l'étude-pilote était de concevoir, de préparer et de mettre à l'essai en situation réelle un espace marécageux pour éliminer l'azote (N) et le phosphore (P) des eaux rejetées par une mine en exploitation. L'élimination des métaux a fait l'objet de tests occasionnels.

Ce rapport présente les résultats de la troisième année; il décrit les résultats d'ensemble et les conclusions de l'étude. De plus, il passe en revue les publications récentes sur les marécages artificiels et sur l'écologie des macrophytes reliées au traitement des eaux usées. À partir des résultats de l'étude-pilote et de l'information des publications courantes, le rapport apporte des critères préliminaires sur la conception des enceintes marécageuses. Les résultats de la première et de la deuxième année sont présentés en détail à part, respectivement dans Norecol (1989) et Norecol (1990).

En 1988, à la mine de charbon Quinsam, on a construit une enceinte marécageuse expérimentale de 800 m^3 à l'intérieur d'un terrain marécageux naturel. On a enlevé la végétation ligneuse existante afin de faciliter la croissance des laîches ou carex (*Carex* sp.), lesquels conviennent mieux au traitement des eaux. Dans l'enceinte expérimentale, on a transplanté des typhas (*Typha*

sp.) afin d'accroître la diversité des espèces du marécage. Une conduite à partir de l'étang de décantation principal de la mine a acheminé l'eau alimentant le marécage expérimental. La profondeur moyenne de l'eau dans ce marécage était de 0,1 m et le temps de rétention (avec les précipitations) s'étendait de 1,7 à 3,4 jours. Dans l'effluent de l'étang de décantation, on a ajouté un fertilisant au nitrate de potassium (KNO_3) afin de produire, dans le terrain marécageux, une alimentation en NO_3-N de 10 mg/L durant la première année et de >20 mg/L (avec un maximum de 120 mg/L) durant la deuxième et la troisième année.

Des échantillons de l'eau de surface, de l'eau souterraine, des sols et de la végétation furent recueillis pour fins d'analyses chimiques. Les échantillons d'eau furent prélevés à l'entrée, au milieu et à la sortie du marécage expérimental. Les échantillons végétaux comprenaient des tissus de typhas, de carex et de myrique baumier prélevés au-dessus et au-dessous de la surface du sol.

La charge et le débit d'azote et de phosphore furent estimés à partir des données de la concentration et de l'écoulement dans la conduite d'arrivée et dans le déversoir. Autant que possible, l'élimination des substances nutritives fut répartie entre les voies microbienne, végétale, exfiltrante et autres; (la composante microbienne et celle de la biomasse végétale souterraine furent estimées seulement par soustraction).

Durant chacune des trois années de l'étude, le marécage a éliminé l'azote de façon très efficace. Sur une base annuelle, le rendement d'élimination de l'azote (N) est passé de 87% durant la première année à 98% durant la troisième année. Il y a eu une certaine variabilité selon les saisons, mais les rendements d'élimination de l'azote étaient supérieurs à 80% même durant les mois d'hiver, tandis que les rendements d'été atteignaient presque 100%. Même si le rendement total d'élimination de l'azote fut toujours élevé, des rejets de petites quantités d'ammoniac (NH_3) et de nitrites (NO_2) se sont produits durant l'hiver.

La plus grande partie de la quantité totale d'azote (84%) a été supprimée par les voies combinées de la dénitrification et de la production de biomasse et de macrofaune souterraines. On estime que, à elle seule, la dénitrification a rendu compte d'au moins 77% de la quantité de N éliminé. La production de tissus végétaux non souterrains a rendu compte de 8,1% du reste de l'élimination de N; l'exfiltration en a rendu compte de 5,9%.

Le marécage a aussi supprimé du phosphore. Cependant, la suppression de P a été beaucoup moins efficace que celle de N. Sur une base annuelle, le rendement de la suppression de P a été de 40% durant la première année, de 48% durant la deuxième année et de 30% durant la troisième année. La diminution du rendement de suppression de P durant la troisième année semble liée à la maturité de la communauté végétale du marécage et semble indiquer un stockage plus faible de P lors de la maturation de la végétation et du microbiote. La végétation non souterraine et l'exfiltration ont rendu compte respectivement d'environ 5,5% et 1% du total de P supprimé. Les voies souterraines (l'assimilation et le stockage dans les racines et les rhizomes des plantes et dans les micro-organismes du sol, et peut-être l'absorption et la formation d'un complexe dans la tourbe du marécage) ont rendu compte de 93,5% de la suppression de P.

La variabilité saisonnière de la suppression de P a été beaucoup plus élevée que celle du rendement de la suppression de N. Les rendements maxima de la suppression de P en été se situaient entre 40% et 50%, mais un rejet net de P vers l'extérieur est survenu durant quelques mois de printemps.

En général, le marécage a eu tendance à supprimer les métaux, mais on a observé une grande variabilité d'un métal à l'autre et selon les saisons ou les années. On a considéré que tous les métaux rencontrés représentaient des conditions de fond naturelles, sans effet important de la part des activités minières. L'aluminium et le fer dissous furent rejetés du marécage durant la saison de croissance mais ils furent supprimés durant le reste de l'année. Le marécage a eu tendance à supprimer le potassium, le manganèse et le zinc (qui étaient présents presque uniquement sous forme de métaux dissous), quoiqu'un certain rejet de zinc en particules soit survenu durant les pluies de printemps et d'automne. Le cuivre a été supprimé dans le marécage durant la troisième année, mais le cuivre en particules a eu tendance à être rejeté vers l'extérieur durant la saison de croissance de la première et de la deuxième année.

L'étude a confirmé des lignes directrices de conception empirique adaptées à partir d'expériences de traitement des eaux usées municipales en terrains marécageux. Les résultats sur l'élimination de l'azote obtenus au cours de cette étude portent sur des eaux usées à basse teneur en azote; ces résultats sont notablement meilleurs que ceux que l'on obtient habituellement avec des eaux usées à forte teneur en azote telles que celles des égouts domestiques. Les résultats conduisent aux recommandations qui suivent. La conception et le dimensionnement des enceintes marécageuses pour la suppression de N devraient se fonder sur les charges et quantités auxquelles on peut s'attendre durant la saison de croissance, et se fonder aussi sur l'hydraulique. À partir des écoulements de pointe en saison de croissance et à partir du haut rendement d'élimination de l'azote observé dans le marécage de traitement de Quinsam, on constate qu'un temps minimum de rétention hydraulique de trois jours devrait suffire pour éliminer l'azote de façon satisfaisante (>80%). Les données que cette étude ont produites pourront en fin de compte se conjuguer à celles que généreront les études à venir sur les terrains marécageux, de façon à produire des critères quantitatifs de conception des enceintes marécageuses pour le traitement des eaux.

ACKNOWLEDGEMENT

This project was funded through the Panel on Energy Research and Development (PERD), Office of Energy Research and Development, Task-2, Oil Sands, Heavy Oil and Coal, and Supply and Services Canada. The report was written by Alan Whitehead. Technical assistance during the course of the study was provided by: Brinco Coal Corporation, especially Jack Cann and the staff at Quinsam Coal Mine; Conservation and Protection, especially Bryan Kelso, Alan Redenbach, Gerry Mitchell, Paul Cluckner and staff of the Environmental Services Laboratory; ASL Laboratories Ltd. and Barbara Szchachor; and staff of Norecol Environmental Consultants Ltd. Expert editorial assistance was provided by Jim Malick, Annette Smith, Bruce Ott, Bob Fuller, Tim Smyth, and Ida Krajsek and administrative support by Joey Dong. This work would not have been possible without the invaluable assistance of the above individuals and others too numerous to mention. For their help and patience, the author is gratefully indebted.

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ii
ACKNOWLEDGEMENT vii
TABLE OF CONTENTS v
LIST OF TABLES xi
LIST OF FIGURES xiii
LIST OF APPENDICES xix

1.0 INTRODUCTION 1-1

- 1.1 Background 1-1
- 1.2 Objectives 1-2

2.0 ECOLOGY OF EMERGENT MACROPHYTES IN RELATION TO THEIR USE IN WATER TREATMENT: A LITERATURE REVIEW 2-1

- 2.1 Introduction 2-1
- 2.2 Description of Emergent Macrophytes 2-1
  - 2.2.1 Overview 2-1
  - 2.2.2 External Anatomy 2-2
  - 2.2.3 Life History 2-2
- 2.3 Growth and Mineral Nutrition 2-5
  - 2.3.1 Plant Growth 2-5
  - 2.3.2 Mineral Nutrition and Tissue Composition 2-7
  - 2.3.3 Decomposition Processes 2-12
- 2.4 Responses to Environmental Stress 2-13
  - 2.4.1 Water Depth 2-13
  - 2.4.2 Salinity 2-15
  - 2.4.3 Temperature 2-16
  - 2.4.4 Toxic Chemicals 2-17
  - 2.4.5 Harvesting 2-18

TABLE OF CONTENTS (continued)

Page

2.5 Implications for Use in Water Treatment 2-19

- 2.5.1 Habitat and Life History 2-19
- 2.5.2 Productivity 2-20
- 2.5.3 Mineral Uptake 2-20
- 2.5.4 Tissue Mineral Content 2-20
- 2.5.5 Secretions into the Environment 2-20
- 2.5.6 Decomposition Processes 2-21
- 2.5.7 Responses to Varying Water Depth 2-21
- 2.5.8 Responses to Salt Stress 2-21
- 2.5.9 Effect of Temperature 2-21
- 2.5.10 Effect of Toxic Chemicals 2-21
- 2.5.11 Effect of Harvesting 2-22

2.6 Overview of Wetland Systems for Wastewater Treatment 2-22

- 2.6.1 Natural Wetlands 2-22
- 2.6.2 Constructed Wetlands 2-23
- 2.6.3 Advantages and Disadvantages 2-24
- 2.6.4 Contaminant Removal Mechanisms 2-25

2.7 Plant Species Selection 2-27
2.8 Constructed Wetland Design Methods 2-27

- 2.8.1 Design Based on Empirical Data 2-27
- 2.8.2 Design Based on Reaction Kinetics 2-30

2.9 Wastewater Types 2-31
2.10 Treatment Performance 2-31
2.11 Operation and Maintenance 2-31
2.12 Selected Case Studies from Western Canada 2-39

- 2.12.1 Domestic Sewage 2-39
- 2.12.2 Mine Drainage 2-39

2.13 Research Needs 2-40

TABLE OF CONTENTS (continued)

Page

3.0 WORK PROGRAM (METHODS) 3-1

3.1 Project Description 3-1

3.1.1 Location 3-1
3.1.2 Wetland Design 3-1
3.1.3 Cattail Transplanting 3-6
3.1.4 Water Conveyance System 3-6
3.1.5 Nitrate Dosing System 3-6

3.2 Operation 3-8

3.2.1 Hydrology 3-8
3.2.2 Water Quality 3-8
3.2.3 Soil Composition 3-10
3.2.4 Vegetation 3-10
3.2.5 Nutrient Mass Balance 3-10

4.0 RESULTS AND DISCUSSION 4-1

4.1 Hydrology 4-1

4.1.1 Surface Inflows and Outflows 4-1
4.1.2 Precipitation 4-1
4.1.3 Evapotranspiration 4-5
4.1.4 Exfiltration and Leakage 4-5
4.1.5 Hydraulic Retention Time 4-5

4.2 Soils 4-6

4.2.1 Soil Organic Matter 4-6
4.2.2 Soil Nitrogen 4-6
4.2.3 Soil Phosphorus 4-12
4.2.4 Soil Metals Content 4-15

TABLE OF CONTENTS (continued)

Page

4.3 Groundwater 4-15

4.3.1 Groundwater pH 4-16
4.3.2 Groundwater Conductivity 4-16
4.3.3 Suspended Solids 4-16
4.3.4 Total Organic Carbon 4-16
4.3.5 Total Nitrogen 4-23
4.3.6 Nitrate 4-23
4.3.7 Ammonia 4-23
4.3.8 Nitrite 4-27
4.3.9 Total Phosphorus 4-27
4.3.10 Total Dissolved Phosphorus 4-30
4.3.11 Orthophosphate (Bio-Available) Phosphorus 4-30

4.4 Vegetation 4-30

4.4.1 Comparison Between Species 4-30
4.4.2 Implications with Respect to Harvesting for Nutrient Removal 4-36
4.4.3 Biomass Productivity 4-39

4.5 Surface Water Quality 4-39

4.5.1 Temperature 4-41
4.5.2 Suspended solids 4-41
4.5.3 Hydrogen Ion Concentration (pH) 4-41
4.5.4 Conductivity 4-45
4.5.5 Dissolved Organic Carbon 4-46
4.5.6 Nitrogen 4-49
4.5.7 Phosphorus 4-57
4.5.8 Metals 4-60

4.6 Nutrient Mass Removal 4-60

4.6.1 Nitrogen 4-60
4.6.2 Phosphorus 4-62

TABLE OF CONTENTS (concluded)

Page

5.0 PRELIMINARY WETLAND DESIGN CRITERIA 5-1

5.1 Background 5-1
5.2 Performance Expectations 5-1
5.3 Design Criteria 5-2
5.4 Construction and Maintenance 5-2

6.0 CONCLUSIONS 6-1

6.1 Nitrogen Removal 6-1
6.2 Phosphorus Removal 6-1
6.3 Metals 6-2

6.3.1 Aluminum 6-2
6.3.2 Copper 6-2
6.3.3 Iron 6-2
6.3.4 Potassium 6-2
6.3.5 Manganese 6-2
6.3.6 Zinc 6-2

6.4 Wetland Design Considerations 6-2

REFERENCES R-1

APPENDICES

A Summary of Kinetics-based Design Approaches for Surface and Sub-surface Flow Constructed Wetlands

B1 Surface Water Quality Data
B2 Groundwater Quality Data
B3 Soil Data
B4 Vegetation Data

C Colour Plates

LIST OF TABLES

Table **Page**

2.2.2-1 Emergent Aquatic Plants of Potential Use in Water Treatment 2-3

2.3.3-1 Estimated Annual Release of Minerals from Decomposing Emergent Macrophytes 2-14

2.6.4-1 Contaminant Removal Mechanisms in Aquatic Systems Employing Plants and Animals 2-26

2.8.1-1 Recommended Hydraulic Loading Rates for Preliminary Design of Constructed Wetlands for Treating Municipal Wastewater 2-28

2.10-1 Ammonia Nitrogen Removal Performance of Wetland Systems Treating Municipal Wastewater 2-32

2.10-2 Total Nitrogen Removal Performance of Wetland Systems Treating Municipal Wastewater 2-33

2.10-3 Total Phosphorus Removal Performance of Wetland Systems Treating Municipal Wastewater 2-34

2.10-4 Metals Removal Performance of Wetland Systems Treating Acid Mine Drainage 2-35

2.10-5 Contaminant Removal Performance of Constructed Wetlands Treating Selected Wastewater 2-36

3.2-1 Water Quality Parameters and Sampling Frequency for Samples Collected from the Experimental Wetland 3-9

3.2-2 Chemical Parameters Measured in Vegetation and Soil Samples Collected from the Experimental Wetland 3-11

LIST OF TABLES (concluded)

Table **Page**

4.1.1-1 Summary of Monthly Inflow and Outflow Volume for the Experimental Wetland for November 1989 to March 1991 4-2

4.2.1-1 Average Soil Organic Matter Content in the Experimental Wetland and Control Site 4-7

4.3.1-1 Groundwater pH Levels in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-17

4.3.2-1 Groundwater Conductivity in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-19

4.3.4-1 Groundwater Total Organic Carbon Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-22

4.4.3-1 Nutrient and Heavy Metal Content of Annual Biomass Production in the Experimental Wetland at Quinsam Coal Mine 1990 to 1991 4-40

4.5.6-1 Statistical Comparison of the Changes in Total Nitrogen Concentrations Occurring in the Upper and Lower Basins and in the Two Basins Combined at the Quinsam Wetland Project January 1990 to March 1991 4-55

4.6.1-1 Nitrogen and Phosphorus Mass Balance in the Experimental Wetland November 1989 to March 1991 4-61

4.6.1-2 Monthly Average Mass and Percent Removals of Total, Nitrate, Ammonia and Nitrite Nitrogen at the Experimental Wetland at Quinsam Coal Mine Between December 1989 and March 1991 4-64

4.6.1-3 Comparison of Nitrogen and Phosphorus Mass Removal Efficiency Among the Three Years of the Wetland Study at Quinsam Mine, August 1988 to March 1991 4-65

4.6.2-1 Monthly Average Mass and Percent Removals of Total, Dissolved and Particulate Phosphorus in the Experimental Wetland at Quinsam Coal Mine Between December 1989 and March 1991 4-69

LIST OF FIGURES

Figure		Page
3.1-1	Location of Quinsam Coal Mine, Vancouver Island	3-2
3.1-2	Location of the Experimental Wetland at Quinsam Coal Mine, Vancouver Island	3-3
3.1-3	Schematic of the Experimental Wetland for Nutrient Removal from Coal Mine Drainage, Quinsam Coal Mine, Vancouver Island	3-4
3.1.4	Detail of Experimental Wetland Berm Construction. Quinsam Coal Mine, Vancouver Island	3-5
3.1-5	Schematic of Potassium Nitrate Dosing System Used at the Experimental Wetland	3-7
4.1.1-1	Flow Measurements Into and Out of the Experimental Wetland for November 1989 to March 1991	4-3
4.1.2-1	Precipitation Record for the Quinsam Minesite for November 1989 to March 1991	4-4
4.2.1-1	Comparison of Soil Organic Matter Content in the Experimental Wetland and Control Site 1990 to 1991	4-8
4.2.2-1	Comparison of Soil Nitrogen Content in the Experimental Wetland and Control Site 1990 to 1991	4-9
4.2.2-2	Seasonal Changes in Soil Nitrogen Content in the Experimental Wetland 1990 to 1991	4-11
4.2.3-1	Comparison of Soil Phosphorus Content in the Experimental Wetland and Control Site 1990 to 1991	4-13
4.2.3-2	Seasonal Changes in Soil Phosphorus Content in the Experimental Wetland 1990 to 1991	4-14

LIST OF FIGURES (continued)

Figure **Page**

4.3.1-1 Groundwater Hydrogen Ion Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-18

4.3.2-1 Groundwater Specific Conductance in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-20

4.3.4-1 Groundwater Total Organic Carbon Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-21

4.3.5-1 Groundwater Total Nitrogen Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-24

4.3.6-1 Groundwater Nitrate-N Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-25

4.3.7-1 Groundwater Ammonia-N Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-26

4.3.8-1 Groundwater Nitrite-N Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-28

4.3.9-1 Groundwater Total Phosphorus Concentrations in Basins 1 and 2 of the Experimental Wetland 1990 to 1991 4-29

4.4.1-1 Nitrogen Content of Cattail, Sedge and Sweetgale from the Experimental Wetland 1990 to 1991 4-31

4.4.1-2 Comparison of Sedge and Sweetgale Nitrogen Content for the Experimental Wetland and the Control Site - March 27, 1991 4-33

4.4.1-3 Seasonal Changes in Vegetation Nitrogen Content of the Experimental Wetland 1989 to 1991 4-34

4.4.1-4 Phosphorus Content of Cattail, Sedge and Sweetgale from the Experimental Wetland 1990 to 1991 4-35

LIST OF FIGURES (continued)

Figure **Page**

4.4.1-5 Comparison of Sedge and Sweetgale Phosphorus Content for the Experimental Wetland and Control Site - March 27, 1991 4-37

4.4.1-6 Seasonal Changes in Vegetation Phosphorus Content of the Experimental Wetland 1989 to 1991 4-38

4.5.1-1 Mean Monthly Ambient Temperature at the Quinsam Minesite for 1991 . 4-42

4.5.2-1 Suspended Solids Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-43

4.5.3-1 Hydrogen Ion Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-44

4.5.4-1 Specific Conductance in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-47

4.5.5-1 Dissolved Organic Carbon Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-48

4.5.6-1 Total Ammonia-N Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-50

4.5.6-2 Nitrite-N Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-52

4.5.6-3 Nitrate-N Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-53

4.5.7-1 Total Dissolved Phosphorus Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4-59

LIST OF FIGURES (concluded)

Figure **Page**

4.6.1-1 Seasonal Total Nitrogen Removal Efficiency of the Experimental Wetland, December 1989 to March 1991 4-63

4.6.1-2 Seasonal Nitrate-N Mass Removal Efficiency of the Quinsam Experimental Wetland, August 1988 to March 1991 4-66

4.6.2-1 Seasonal Total Phosphorus Removal Efficiency of the Experimental Wetland, December 1989 to March 1991 4-68

LIST OF FIGURES IN APPENDIX B-1

Figure **Page**

B-1-1 Total Aluminum Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 2

B-1-2 Dissolved Aluminum Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 3

B-1-3 Total Copper Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 4

B-1-4 Dissolved Copper Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 5

B-1-5 Total Iron Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 7

B-1-6 Dissolved Iron Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 8

B-1-7 Total Potassium Concentrations in the Effluent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 9

B-1-8 Dissolved Potassium Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 10

B-1-9 Total Manganese Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 12

B-1-10 Dissolved Manganese Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 13

B-1-11 Total Zinc Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 14

B-1-12 Dissolved Zinc Concentrations in the Influent, Midpoint and Effluent of the Experimental Wetland 1989 to 1991 15

LIST OF FIGURES IN APPENDIX B-3

Figure **Page**

B-3-1 Comparison of Soil Aluminum Content in the Experimental Wetland and Control Site 1990 to 1991 2

B-3-2 Seasonal Changes in Soil Aluminum Content in the Experimental Wetland 1990 to 1991 3

B-3-3 Comparison of Soil Copper Content in the Experimental Wetland and Control Site 1990 to 1991 5

B-3-4 Seasonal Changes in Soil Copper Content in the Experimental Wetland 1990 to 1991 6

B-3-5 Comparison of Soil Iron Content in the Experimental Wetland and Control Site 1990 to 1991 8

B-3-6 Seasonal Changes in Soil Iron Content in the Experimental Wetland 1990 to 1991 9

B-3-7 Comparison of Soil Potassium Content in the Experimental Wetland and Control Site 1990 to 1991 10

B-3-8 Seasonal Changes in Soil Potassium Content in the Experimental Wetland 1990 to 1990 12

B-3-9 Comparison of Soil Manganese Content in the Experimental Wetland and Control Site 1990 to 1991 13

B-3-10 Seasonal Changes in Soil Manganese Content in the Experimental Wetland 1990 to 1991 14

B-3-11 Comparison of Soil Zinc Content in the Experimental Wetland and Control Site 1990 to 1991 16

B-3-12 Seasonal Changes in Soil Zinc Content in the Experimental Wetland 1990 to 1991 17

INTRODUCTION

1.1 Background

Nutrient release, especially of nitrogen, has been identified as a significant concern at surface coal mines in Canada. Discharges and seepage, especially from open pits, stockpiles and waste rock dumps, can contain large amounts of nitrogen from mining operations. The main sources of nitrogen are blasting agents such as ANFO (ammonium nitrate and fuel oil) or slurry gel. From 1 to 6% of the total nitrogen in such explosives have been shown to enter the receiving environment from operating mines (Pommen 1983; Ferguson and Leask 1988). These nutrients, when released into surface waters, have the potential to significantly degrade water quality and aquatic habitat (Nordin 1982).

Receiving water quality associated with coal mines has become a greater concern to regulatory agencies. This greater concern, along with the apparent lack of economic treatment methods or proven, effective mitigative measures, has led to delays in obtaining environmental approvals for developing mines as well as to additional monitoring and permit requirements for existing mines. Since nitrogen-based explosives are likely to continue in wide use, effective mitigative measures to reduce nitrogen at source and treatment for nitrogen removal from wastewaters will be of increasing importance. However, cost-effective techniques have not been identified for nitrogen removal (E.P.A. 1975), especially on the scale necessary for a surface mine. Alternatives to conventional approaches, therefore, need to be identified and evaluated.

Wetlands have been identified as a promising approach for mine water treatment with the main attractions being low capital, operating and maintenance costs. Experience with natural or constructed wetland systems for nutrient removal from waste waters has been limited, especially in Canada. As a result of the interest but lack of information regarding the feasibility of using wetland systems, Environmental Protection of Environment Canada, Pacific Region, retained Norecol Environmental Consultants Ltd. in 1986 to carry out a program to assess the use of wetlands for nutrient removal from mine drainage. The first two years included literature and laboratory research on the use of alternative approaches, including upland irrigation and wetlands, for mine water treatment (Norecol 1987a and b). The promising results of the wetland assessment have led to the establishment of a three-year pilot wetland study.

The results of Years 1 and 2 of the pilot wetland study were detailed in the respective annual reports (Norecol 1989, 1990). The findings of Year 3 are presented in this report, and the results are compared with Years 1 and 2.

1.2 Objectives

The overall objective of the pilot study was to design and test the wastewater treatment efficiency of a field scale wetland at an operating surface coal mine.

Specific objectives were to:

- quantify the removal of nitrogen and phosphorus from wastewater passing through the pilot wetland, as affected by season of year;
- quantify the contribution of the plants to the overall nitrogen and phosphorus removal;
- investigate the effect of water retention time on treatment performance; and
- develop design criteria for the construction of full scale wetland systems for coal mine wastewater treatment.

The study was also intended to provide information on wetlands operation and maintenance requirements as well as on plant survival and growth relative to waste water characteristics.

ECOLOGY OF EMERGENT MACROPHYTES IN RELATION TO THEIR USE IN WATER TREATMENT: A LITERATURE REVIEW

2.1 Introduction

The literature review is subdivided into four main sections: a general description of emergent macrophytes, growth and mineral nutrition, responses to environmental stress, and a discussion of implications for coal mine wastewater treatment. The reader is referred to the appropriate section of the previous review (Norecol 1987b) for specific examples of emergent macrophyte use in wastewater treatment.

An attempt has been made here to emphasize aspects of the ecology and physiology of emergent species which are of demonstrated or potential importance in the design, management and/or treatment effectiveness of a wetland system.

2.2 Description of Emergent Macrophytes

2.2.1 Overview

Emergent macrophytes grow in nearly monospecific stands in areas where the water table is at or above ground level. Plant size can vary between species from 0.3 to >2.5 m above ground level. New populations begin from seed, whereas existing stands grow and are maintained primarily through vegetative reproduction. Thus, most plants within a stand will be genetically identical clones. Genetic differentiation is more likely to be found between populations from different geographic locations. Some species, such as the cattails and rushes, are aggressive colonizers of newly created flooded habitats.

The plants are perennial, though the above-ground biomass may die back after the growing season. The rhizome or rootstock provides the nutrient reserves used for initiating vegetative growth in the spring. Flowering, which does not necessarily occur in every plant within a population, takes place during the summer. Seeds are dispersed by wind, water, wildlife, and human activities.

2.2.2 External Anatomy

The terminology used in describing aquatic plants is often confusing, due to the diversity of plant forms and of scientific backgrounds of the investigators. This section provides a generalized description of the morphology and life history of emergent macrophytes, defining terms as they are used in this review. The information in this section originates from the publications of Weldon et al. (1973), Morton (1975), Bayly and O'Neill (1972), and Dickerman and Wetzel (1985).

The main emergent macrophyte species which have been identified for potential use in water treatment are listed in Table 2.2.2-1. All of the identified species share above- and below-ground morphological features. The above-ground parts are generally long, slender and unbranched, and emerge above the water level for most (if not all) of their length. In many species, such as the bulrushes, rushes and sedges, there is no clear distinction between "stem" and "leaf". However, cattails show distinct leaves and no real stem, while the giant reed has a true stem with leaves. Generally speaking, the stems or stem-like plant parts that are circular in cross section are known as "culms". Flowers and fruiting bodies are borne either on specialized "spikes", as in the cattails, or as branches (e.g. rushes and sedges) or elongations of a culm (e.g. bulrushes). The meristem (zone from which leaf or culm cell production takes place) can be apical (at the tip of the stem, as in *Phragmites*), to basal (at the base of the plant, as in cattails, bulrushes and sedges). The location of the meristem on the shoot is important in relation to multiple harvests.

The below-ground portions of the plants consist of the larger rootstock or rhizome and the smaller roots. The rhizome functions primarily as a storage organ, while the roots are involved in both nutrient uptake and anchoring. Vegetative reproduction occurs from buds on the rhizome, each daughter plant being a clone or "ramet" of the parent plant. The horizontally oriented rhizomes grow laterally at rates which vary with species. The ramets may be produced in clusters or "stools" (e.g. *Juncus, Pharagmites*) or in more evenly spaced single shoots (e.g. *Typha*). Rhizomes are not necessarily always found in emergent species, as for example in the native B.C. wool grass, *Scirpus cyperinus* (Taylor 1983).

2.2.3 Life History

Most species are perennial, maintaining a viable below-ground biomass during the winter. Flowering takes place in summer, and pollination is effected by wind and insects. The plants are generally dioecious (having male and female flowers on the same plant), but asexual budding is the predominant mode of reproduction. The seeds are either buoyant or sinking, and are dispersed by wind, water movement and wildlife.

TABLE 2.2.2-1

EMERGENT AQUATIC PLANTS OF POTENTIAL USE IN WATER TREATMENT

COMMON NAME	SCIENTIFIC NAME
Cattail	*Typha sp.*
Giant reed	*Phragmites sp.*
Bulrush	*Scirpus sp.* *Schoenoplectus sp.*
Rush	*Juncus sp.*
Sedge	*Carex sp.* *Cyperus sp.*

The onset of flowering has been sparsely studied in aquatic vegetation (Sculthorpe 1967, Hutchinson 1975). The primary factors causing flowering are thought to include photoperiod, temperature and nutrition. Warm temperatures and long days are thought to favour the photosynthetic rates which will allow for the maturation of reproductive organs.

While the foregoing provides an overview of the generalized plant form, detailed descriptions of the life history of cattail and giant reed are summarized below.

Typha (cattail) is described by Dickerman and Wetzel (1985) as a rhizomatous perennial that forms dense, nearly monospecific stands. Though seedlings are important in the initial phase of site colonization, the maintenance of a mature stand is achieved by vigorous vegetative growth. The shoots arise from the apices of lateral rhizomes, and generally die back at the end of the growing season. The shoot is composed of up to 16 leaves (the number differing between species), and can exceed 2.5 m in height (Morton 1975). The flower is in the form of an apical spike. Carbohydrate reserves in the rhizome support the rapid development of leaves in the early spring. Hence, maximum leaf area is available when conditions are most favourable for high photoshythetic rates.

A description of the life history of cattails has been provided by Yeo (1964, in Hutchinson 1975). He presented a schematic plan of the rhizome development showing that up to 10 lateral rhizomes may develop from a single node in the parent rhizome.

Phragmites communis has been described as a system of relatively deep, long-lived rhizomes from which stiff annual shoots arise (Hurlimann, 1951 in Bayly and O'Neill 1972). Shoot heights of up to 4 m have been reported (Bjork 1967, in Hutchinson 1975). Each year the rhizome advances a short distance before turning upwards; another bud is formed where a shoot will arise. Branching sometimes occurs behind the horizontally growing apex producing additional annual bud sites. The main aerial shoot from the terminal bud dies back in the fall and a number of lateral buds are formed as a stool at its base. New buds form in the stool each spring over about six generations, after which the stool no longer produces shoot forming buds. Each shoot consists of a stiff stem with an apical meristem and distinct leaves. Flowers develop from the stem apex, in the form of a plume-like pinacle. Seeds of *P. australis* have been found to germinate only in unflooded soils (Spence 1964, in Hutchinson 1975).

The aforementioned two species are examples of macrophytes exhibiting basal and apical growth, and separate and attached fruiting bodies. Most other emergent plants of interest for water treatment can be categorized accordingly.

2.3 Growth and Mineral Nutrition

2.3.1 Plant Growth

The variation in plant size between species is reflected in the number of plants and in the biomass that can be measured on an areal basis. The smaller species therefore, such as some rushes and sedges, show a higher density of stems per unit area and a lower dry matter mass than the larger species such as the giant reed, bulrushes and cattails.

The amount of biomass produced in any stand depends on the soil and water fertility, the impact of browsing animals, plant genetics, and the stability of the environment. Changing water depths, for example, may in some instances alter the interspecific dominance relationships, suppressing production of one species while favouring that of another. In general, shoot growth increases rapidly during the first half of the growing season, and then decreases or ceases all together, with subsequent growth being directed to seed production and storage in the rhizome. The below-ground biomass can represent less than 10% to more than 70% of the total biomass within a stand. Dry matter productivities can range from <1 to 6 kg dry matter/m^2/yr. Conversely, loss of dead biomass through physical and microbiological decay can exhibit a similar range of values. An equation for predicting shoot biomass as a function of shoot height and leaf number is available for *Typha latifolia* (Dickerman and Wetzel 1985).

Shoot production in *Typha latifolia* has been studied by Boyd and Hess (1970) at over 20 different sites in the southeastern United States. Biomass ranged between 428 - 2252 g/m^2, and was highly correlated with soil and tissue phosphorus (P) content. Water depth (5 to 76 cm) had no effect on the standing crop. While nutrients in the soil and water correlated with the standing crop, other factors such as browsing and genetics, were also considered to be important. The use of total dissolved phosphorus (TDP) as a measure of available P was recommended. Regression equations were derived for defining nutrient mass (g/m^2) as a function of standing crop, and tissue mineral content as a function of tissue N content.

Growth (shoot biomass) of cattails in a South Carolina reservoir was found to increase rapidly until mid June and then level off (Sharitz et al. 1984). *Typha latifolia* growth in south-central Michigan was found to take place in three annual pulses of ramet (clone) emergence (Dickerman and Wetzel 1985). The first shoot cohort emerged in early spring, followed by a second in mid summer and a third in late summer to early autumn. At the end of the growing season the first cohort died completely, while the second and third exhibited about 80% and <25% mortality, and there was no wintertime mortality of immature shoots. Mean shoot densities of the successive cohorts were 22 (first cohort), 2.1 to 12.6 (second cohort) and 10.4 to 24.1 (third cohort) (new shoots/m^2). Overall average shoot densities ranging from 11.2 to 43.9 stems/m^2 were recorded. It was determined that shoot density does not regulate ramet (clone) populations in mature cattail stands. A non linear regression equation ($r=0.92$, $n=1455$) describing shoot biomass as a function of shoot green height (i.e. height of tallest live leaf) and leaf number was derived:

$$Y = 0.00014\ X^{1.79}\ Z^{1.13}$$

where Y is the shoot biomass in grams ash-free dry weight, X is the green leaf height, and Z is the number of leaves.

Yeo (1964, in Hutchinson 1975) studied the development of a single *Typha latifolia* seedling over a one year period. As with the work of Dickerman and Wetzel (1985), three ramet cohorts were reported: 26 emergent shoots having a height >46 cm, 29 shoots of <46 cm, and 37 non-emergent shoots. (Details on timing and environmental conditions were not available.)

Barko and Smart (1978) studied the growth and biomass distribution of *Scirpus validus* and *Cyperus esculentus* on sand, silty clay and clay under laboratory conditions. Growth of both species was greatest on silty clay, followed by clay and sand. Shoot density ranged from 231 to 947 stems/m^2 for *Scirpus* and from 191 to 2983 stems/m^2 for *Cyperus*. Finer textured soils were correlated with increased plant growth. The ratio of below to above-ground biomass was inversely related to plant growth. Nitrogen (N) was considered to be more limiting than P, as P was readily adsorbed in all three test soils; (no distinction was made between available and non-available P).

Productivities of seven marsh plant species were measured by Hopkinson et al. (1978) in coastal Louisiana. The species included *Juncus roemerianus*, *Phragmites communis*, *Sagitaria falcata*, *Spartina alterniflora*, *Spartina cynosuroides*, *Spartina patens*, and *Distichlis spicata*. In five of the species, peak biomass (standing crop) was recorded in summer, the range for all species being 648 to 1376 g/m^2 (live biomass). The ratio of annual mean live to dead biomass ranged from 0.21 (*Phragmites communis*) to 0.91 (*Juncus roemerianus*). Plant gross productivities ranged from 1501 to 6043 g/m^2/yr while disappearance rates (i.e. biomass loss through fragmentation and microbial decomposition) ranged from 1572 to 5138 g/m^2/yr. Of interest in the context of water treatment was the observation by these authors that *Phragmites communis* and *Spartina cynosuroides* had the lowest loss rates of dead material (and by inference the lowest nutrient recycling rate).

Photosynthesis and respiration in *Scirpus acutus* have been studied in situ in Michigan by Filbin and Hough (1982). The maximum carbon (C) fixation rate of 0.59 mg C/gh was measured in June, and decreased thereafter. No correlation was found between net productivity and temperature or light. The authors noted that the evolution of carbon dioxide (CO_2) from aerobic respiration in the rhizosphere may increase the release of CO_2 via the leaves. The fate of light in a stand of *Phragmites communis* was investigated by Ondok (1973) in Czechoslovakia. Between 87.4 and 94.3% of the direct and indirect radiation falling on the mature stand was absorbed, and 5.1 - 10.6% was reflected.

2.3.2 Mineral Nutrition and Tissue Composition

Mineral Nutrition

The availability of minerals for uptake depends on such factors as soil and water pH, conductivity, organic matter content and the relative concentrations of the various elements in the soil and water. Metals may be taken up more readily under oligotrophic than under eutrophic conditions. Temperature can have an overriding effect on mineral uptake relative to other factors; the uptake rate increasing with increasing temperatures (within a species' tolerance range).

Emergent vegetation can concentrate various elements in the below or above-ground tissues. Though there are differences between species, certain metals are translocated no further than the root-zone (e.g. Cu, Ni, Pb, Cd), while others (e.g. Zn, Na, Mn) are accumulated in the shoot. The reduced mobility of certain elements beyond the root zone may be related to chelation in the root cell walls and to the root endodermis acting as a barrier. The increased mobility of others may be associated with the pumping effect of transpiration through the leaf stomata. Relative accessibility of elements to the xylem or phloem of the tissue also may affect the mobility of certain elements. Those elements which exist in nature as oxyanions (e.g. As, Mo, Se) are readily translocated to the shoots. As with P, other elements such as Cu, Ni and Co in the water or soil, are not 100% available to the plants. The optimum N:P ratio in wastewater to be treated by emergent vegetation systems is between 10:1 and 15:1 in order to maximize the removal of both N and P from the water.

Taylor and Crowder (1983) have summarized the mineral nutrition of *Typha latifolia* as follows:

> "Generally spring growth is characterized by mobilization of carbon reserves and mineral nutrients from the soil-sediment. At this time, accumulation of mineral nutrients by aerial tissues exceed that required to sustain the current growth. As the aerial tissue becomes self-supporting, mobilization from the rhizome gives way to translocation of carbon compounds and mineral nutrients from leaf tissue to the developing reproductive shoot and once again back to the rhizomes (or dormant overwintering buds) for winter storage."

Emergent plants obtain nutrients from the soil and water in which they grow. The plants can grow vigorously in hydroponic culture as well, as reported for *Typha orientalis* (Cary and Weerts 1984) and *Phragmites communis* (Wolverton 1982). *Phragmites communis* exhibits water roots that do not grow in the soil and which respond differently to certain environmental conditions than do soil roots (Merezhko et al. 1978).

The availability of minerals to the roots is dependent on such factors as soil pH, conductivity, organic matter content, and the relative concentrations of the various elements in the soil and interstitial water.

In a study comparing the mineral nutrition of *Phragmites communis* growing in oligotrophic and eutrophic environments in Denmark, Schierup and Larsen (1981) found that metals were taken up more readily under oligotrophic conditions despite lower ambient mineral concentrations at the latter site. Below-ground tissue concentrated Cu, Pb and Cd, while Zn was largely concentrated in the upper leaves and stem. The translocation of Zn to the upper plant was thought to be associated with the plant hormone IAA (indole acetic acid), of which this metal is an important component. The reduced translocation of Cu, Pb and Cd beyond the root zone may be related to a combination of chelation in the root cell walls, and to the action of the root endodermis as a barrier.

Temperature was found to be more important than soil N and P content in determining the growth and mineral uptake by *Typha latifolia* (Adriano et al. 1980). In a laboratory study, an increase from 19° to 25°C yielded 1.7 times more biomass, while an increase from 18° to 32°C resulted in a 2.2 times increase in shoot biomass. The authors cite research indicating that growth reduction at higher temperatures may be due to depletion of carbohydrate reserves. Thermal sensitivities of specific isoenzymes of malate dehydrogenase have been shown to determine the thermal tolerance differences between two species of *Typha* (Liu et al. 1978).

The optimum concentrations of macronutrients of *Typha orientalis* grown in greenhouse hydroponic culture in Australia were 70 mg N/L and 20 mg P/L at 25 - 28°C (Cary and Weerts 1984). Citing from other research, the authors observed that *T. latifolia* grew better at 32° than at 25°C. Walrath and Natter (1976) suggested that the optimum N:P ratio in a wastewater to be treated in macrophyte systems should be 10:1 - 15:1 in order to maximize the uptake of both N and P. Lower ratios would result in decreased P removal while higher ratios would lead to reduced N removal.

Tissue Mineral Content

Tissue mineral content is usually positively correlated with ambient concentration in either water or soil. Below-ground tissues generally have higher concentrations of most elements than do the shoots. The various reports, however, do not reveal a consistent pattern either within or between species. High natural variability in tissue mineral content generally requires very intensive sampling to allow detection of statistically significant differences.

Generally, (though not always) the concentrations of macronutrients (N, P, K) in the above-ground tissues are highest early in the growing season and decrease thereafter due to a dilution effect as the nutrient reserves are distributed throughout the increasing biomass. Marked decreases may occur in association with fruiting, the fruiting organs exhibiting high nutrient concentrations (though a low biomass) relative to other plant parts. Minerals such as Ca, Na, Mg and Mn tend to increase in the shoots over the growing season. Root-rhizome N and P content decreases during flowering. Rhizomes may store 40 to 70% of the peak above-ground stock of macronutrients.

Interaction effects between soil elements can affect plant uptake of a particular element (e.g. high Zn may inhibit Cd uptake). Live tissue P, K, Ca and Mg may be affected by soil potassium content, and tissue N, Cu, Fe and Mn may be affected by soil Ca content. Dead tissue mineral content is affected more by leaching (particularly K), wind-borne deposition and microbial decomposition.

Equations for predicting tissue mineral content and mineral stocks per unit area on the basis of tissue N content and standing crop are available for *Typha latifolia* growing at northern latitudes (Boyd and Hess 1970).

Soil mineral content appears to be the primary determinant of live tissue mineral content (McNaughton et al. 1974, Auclair 1979, Babcock et al. 1983). Dead tissue mineral content is affected more by timing and cause of death, and by physical and microbiological decay, than by soil mineral content. As mentioned above, temperature can also have an important effect in certain species (Liu et al., 1978). In hydroponic culture, tissue N and P content is related to the concentration of these nutrients in the growing medium (Cary and Weerts 1984). Regression equations for predicting tissue mineral content on the basis of tissue N content have been derived by (Boyd and Hess 1970) for *Typha latifolia* in the southeastern United States.

Auclair (1979), in a field study on *Typha angustifolia*, *Scirpus fluviatilis*, *Equisetum fluviatile*, *Eleocharis palustris* and *Scirpus validus*, found that soil nutrient content was 4 to 5 times more important than community structure in determining tissue nutrient content. Soil K had the highest correlation with tissue, P, K, Ca and Mg, while soil Ca had the highest correlation with tissue N, Cu, Fe, and Mn.

Cattails growing in a coal ash settling basin in South Carolina (Guthrie and Cherry 1979) were found to concentrate the most K, Ca, Ba, Mn, Cl, Se, and Br, in comparison with duckweed, bald cypress, *Pontederia* and the algae *Oscillatoria* and *Hydrodyction*. Arsenic was concentrated least by cattail and most by duckweed. Synergistic toxic effects of Cu - Zn and Cu - Hg were suggested as possibly inhibiting the establishment of other species.

Typha domingensis was categorized as an Mn accumulator by Hocking (1981). The leaves accumulated 73% of the total plant Mn. Over a range of Mn concentrations from 0.10 to 10 mM in the laboratory rooting medium, Mn was found to reduce growth at only the most concentrated level. At this level (10 mM Mn), the mineral was accumulated in the roots at a faster rate than in the rhizomes or leaves. The concentration of Ca, P and Mg in the leaves, roots and rhizomes decreased with increasing ambient Mn. During senescence, leaf N, P and K content decreased by 65 - 84%, while Na, Mn, and Ca levels increased. The decreases were attributed to translocation to the roots; (leaching was not a factor as no rain had fallen during the field experiment). The accumulation of xylem-mobile Na, Cl and Mn in leaf tissue was likely due to the pumping effect of transpiration. The author suggested that the greatest removal of phloem-mobile minerals such as N, P, K and Mg might be achieved by harvesting the shoots just as they reach full size. Within the context of feeding the leaves to animals, concern was expressed at the potentially toxic Mn levels in the shoots (as the recommended dietary intake for stock, of 1 mg/g dry weight, could easily be exceeded; mixing with a low-Mn feed ingredient such as barley or wheat was suggested).

Leaf mineral content in *Typha latifolia* decreases as the crop matures (Sharitz et al. 1984), and a marked decrease is observed before fruiting (Boyd and Hess 1970).

Shoot N, P and K content in cattails declined rapidly during the first two months of growth (March and April in South Carolina) and then gradually during the remainder of the growing season (Sharitz et al. 1984). The sharp decline in shoot nutrient content was attributed to dilution throughout an increasing biomass and possibly a decline in absorption rate. Root N and P content showed a major decrease during pre-reproductive and flowering stages. Losses of tissue K were attributed to leaching. Calcium increased in shoots and rhizomes over the growing season, while Mg increased in the shoots and remained constant in the roots.

Decreases in tissue mineral content from May to August were recorded by Mudroch and Capobianco (1979) in both submerged and emergent species in the Moira River (Lake Ontario), an area historically associated with mining and smelting. Dilution was indicated as the probable cause of the decreases. Submerged species concentrated trace elements (Fe, Au, Cu, As, Ag, and Ni) to a greater extent than emergent species. Only above ground tissues were sampled. Copper, Ni and Co in the sediment were determined to be 71.3%, 56.3% and 81.6% labile (i.e. available to the plants).

Correlations between metal content in the soil and in *Typha latifolia* growing in wetlands in the Sudbury, Ontario region were studied by Taylor and Crowder (1983). Plant tissues analysed included root, rhizome, shoot (base, mid and tip), flower (male and female) and pollen. Three classes of sediment-plant interaction were identified. First, no correlation was found in the case of N, Mg, and Ca. Second, a significant correlation was found between Cu and Ni content in the soil and in the below-ground plant organs (roots and rhizomes). Third, a significant correlation was found between Fe and Mn content in the soil and in virtually all plant tissues. No correlation was found between soil pH, Eh (conductivity) and plant metal uptake (contrary to the findings of other studies). With the exception of Mn and Ni in the shoot tips, the highest metal concentrations were consistently found in the plant roots. The authors infer that site-specific interaction effects may be stronger than isolated environmental factors in determining the magnitude of mineral uptake. Shoot tips, fruiting bodies and flowers showed generally higher metals content than other above-ground plant parts. Transpiratory pumping of mobile elements was advanced as a possible explanation for the higher metals content in the older shoot parts. Washing of shoot tips prior to chemical analysis removed significant amounts of Ni and Fe. These authors also cite research indicating that *T. latifolia* roots continue to absorb P from above-ground tissues past senescence into early winter. Rhizomes may store from 40 to 70% of the peak above-ground stock of macronutrients.

In *Phalaris arundinaceae* (reed canary grass), an emergent species that grows in Scottish lochs (Ho 1979) and is widely distributed in North America, the tissue mineral content increased during the growing season, peaking in late summer and then decreasing with the onset of senescence. The content of C, P, Na and Fe in shoots peaked in July - August, while N, K, Ca and Mg peaked in August.

The uptake of trace elements (As, Cd, Cr, Cu, Fe, Mn, Ni, Se, and Zn) by *Typha latifolia* was compared in coal ash-impacted and non-impacted marshes in South Carolina by Babcock et al. (1983). In this particular study, rhizome samples were peeled prior to analysis in order to eliminate the error due to external adsorption. Tissue mineral content was higher in samples from the impacted areas. It was found that those elements which exist in nature as oxyanions (As, Mo, Se), as well as, Cu, were translocated to the shoots, while most other elements were concentrated in the rhizomes.

Cadmium content was lower in plants from impacted areas, possibly due to an interaction effect with high soil Zn at the contaminated site, such that high Zn inhibited Cd uptake. The authors conclude that the relative concentrations of chemically similar elements may be quite important in terms of their effects on plant mineral uptake.

Root Secretions

Inorganic molecules such as P and Mg, as well as organic compounds are secreted into the aquatic and soil environment by emergent plants. Organic carbon and cAMP (cyclic adenosine monophosphate) secretions are potentially important as sources of nutrients and as community growth regulators, respectively. Up to 30 - 40% of the carbon production can be released back into the environment as DOC (dissolved organic carbon).

Francko and Wetzel (1984) studied the release of organic compounds from the root-rhizome of *Scirpus subterminalis*, with particular emphasis on cAMP (a regulatory effector molecule involved in maintenance of homeostasis, including hormonal responses, membrane permeability changes and the regulation of C, N and P metabolism). Marked diurnal fluctuations were found in the cell content of cAMP and in cAMP release rates. Peak release took place at about 1800 hrs in *Scirpus* and about 2400 hrs in the submerged species *Najas flexilis*. Organic carbon was also secreted by *Scirpus*, with similar timing to cAMP but not at similar rates, indicating that the secretions of the two classes of compounds were not necessarily related. Comparison of washed and unwashed specimens of *Scirpus* revealed that, in intact plants, the epiphytic flora was associated with a daytime decrease in cAMP release rates and with high plant tissue cAMP content at night. It was concluded that the uptake of cAMP by the microflora was associated with its photosynthetic activity. This study provided evidence for the important role played by extracellular secretions and by the epiphyton in emergent macrophyte communities.

Mickle and Wetzel (1978a, 1978b, 1979) conducted extensive work on the interaction of angiosperm-epiphyte complexes in the exchange of nutrients. The authors found that while DOC generally increased over time in laboratory units containing *Scirpus subterminalis* or *Myriophyllum spicatum* (a wholly submerged species), the increase was limited to organic compounds having a molecular weight >1000. The source of DOC was considered to be senescence and autolysis (to the extent that 30 to 40% of the production could be released via the latter process). The export of DOC was not evident when the plants (and associated epiphyton) were metabolically most active.

Release of Mg and P from *Phragmites communis* roots to the soil is suggested by data from Ontario (Bayly and O'Neill 1972). Export of oxygen from the roots of *Typha* into the adjacent soil also appears to occur (Sale and Wetzel 1983).

2.3.3 Decomposition Processes

The decomposition of aquatic plants results from physical fragmentation, biodegradation and leaching mechanisms, which recycle minerals and compounds to the environment. Submerged litter decomposes at a faster rate than emergent litter. The rate at which species decompose, both above and below water, varies. Rapid decomposition is often associated with submergence and high tissue N content. Potassium and sodium tend to leach rapidly from plant litter. In unmanaged (i.e. unharvested) stands of certain species (e.g. *Typha*, *Phoragmites*, *Scirpus*), the disappearance of standing biomass may proceed at a relatively slow rate of less than 14 to 20% per year. Estimates are available for nutrient releases (or accumulations) from decomposing plant litter of *Scirpus* and *Typha*.

The decomposition of *Typha glauca* and *Scirpus fluviatilis* has been studied under field conditions in Iowa (Davis and van der Valk 1978), using free-standing plants and litter placed in submerged and suspended net bags. *Typha* was found to decompose more rapidly than *Scirpus*. After 525 days, only 14% and 20% of the original wild (i.e. not in bags) standing biomass of *Scirpus* and *Typha*, respectively, had been lost due to weathering and decomposition processes. A similarly low fraction of the original nutrients was lost during the experimental period. Litter in the submerged bags decomposed faster than in the suspended bags. Nutrient releases (or accumulation) from decomposing plant litter were estimated, as shown below in Table 2.3.3-1. The increases in litter nutrient content, with the exception of Ca, were attributed to contamination of submerged litter by silt. Calcium accumulation was found in the suspended litter, and was attributed to deposition from spray, generated by raindrop impact on the surrounding water and vegetation.

Rapid decomposition has been associated with high leaf N content, while lower disappearance rates have been noted in species that do not fall over on dying, such as *Phragmites communis* (Hopkinson et al. 1978). Increases in substrate (soil and water) Mg content during a summertime investigation of a *Phragmites communis* marsh in Ontario were attributed to decay of organic matter and possibly export from the live plants (Bayly and O'Neill 1972). Potassium and Na have been recorded to leach rapidly from decomposing tissue of *Scirpus subterminalis* (Mickle and Wetzel 1978a).

2.4 Responses to Environmental Stress

2.4.1 Water Depth

Changes in water depth can affect community structure in wetlands. Periodic drought may contribute to the maintenance of species diversity in natural wetlands. Certain species of emergent vegetation respond to increasing water depth by allocating more resources and energy to the leaves while decreasing resource allocation to asexual or vegetative reproduction.

TABLE 2.3.3-1

ESTIMATED ANNUAL RELEASE OF MINERALS FROM DECOMPOSING EMERGENT MACROPHYTES

(Davis and van der Valk 1978)

NUTRIENT	*Scirpus* (kg/ha/yr)	*Typha* (kg/ha/yr)
N	10	71
P	9(8)*	10
K	-	123
Na	11	94
Ca	(55)	-
Mg	(5)	41
Fe	(>11)	(20)
Al	(>13)	(21)

* Values in ( ) are accumulations.

- Not given.

Typha latifolia and *T. angustifolia* in Michigan were both found to allocate nutrients and energy differently in response to increasing water depth (Grace and Wetzel 1982). Plants in deeper water had taller leaves, increased resource allocation to the leaves, decreased allocation to sexual reproduction, and decreased allocation to vegetative reproduction.

Fulton et al. (1983) studied species dominance patterns of rooted vegetation in strip mine impoundments containing *Typha glauca*, *Sparganium eurycarpum*, *Scirpus fluviatilis* and *Scirpus validus*. Periodic drought was thought to maintain species diversity by allowing a subdominant or temporarily absent (except in seed form) species such as *S. validus* to re-establish a living population.

2.4.2 Salinity

Tolerance to high ambient salinity varies within and between species, with the reed *Phragmites australis* and the sedge *Cyperus involucratus* showing high tolerances, and *Typha* exhibiting slight to moderate salt tolerance. A common physiological response to salt stress is increased water content in the plant tissues. Nitrate accumulation in leaf tissues is often associated with high ambient NaCl concentrations, a phenomenon also observed in terrestrial plants.

Typha domingensis in Australia was determined to be slightly salt-tolerant (Hocking 1981). In plants exposed to a salinity range of 0.5 - 100 mM NaCl in the laboratory, growth was not significantly reduced until salt concentrations exceeded 50 mM. At 100 mM NaCl, most roots died "within a few days", and the shoots were stunted and showed necrotic, curled tips. Sodium was more toxic than chloride. Rhizomes had the lowest, and leaves the highest, levels of Na and Cl. Sodium can retard plant growth through its effects on osmotic adjustment, ion uptake, enzyme activity and hormonal balance. Citing other research, the author advised using a more salt tolerant species such as *Phragmites australis* if the wastewater to be treated exhibits elevated salinity levels.

The effects of sodium and potassium chlorides on *Cyperus involucratus* were subsequently investigated by Hocking (1985). The upper concentration limits for vigorous growth were 75 mM NaCl and 100 mM KCl. As with *Typha*, Na was the most damaging ion, followed by Cl and K; NaCl was more detrimental to growth than KCl. Shoot:root ratio of Na and K decreased from 6:1 and 4:1, respectively, at the lowest concentrations to approximately 2:1 (both elements) at the higher (>100 mM) concentrations. The shoots contained 60% or more of the total plant content of Na, Cl, K, Ca, Mg, N and P. Extrapolating from the laboratory results, it was estimated that, in a wastewater containing 25 - 50 mM NaCl or KCl, a harvest of *C. involucratus* could remove 44.6 g Cl and 78.4 g Na per m^2.

Salt stress has been associated with accumulation of nitrogen in the roots and rhizomes of *Typha domingensis* (Hocking 1981) and in all organs except the roots in *Cyperus involucratus* (Hocking 1985). In the latter study, elevated shoot (leaf and bud) nitrate content was also recorded under NaCl but not KCl-stressed conditions, as had been found with other plants. The inference was made that high Na levels diminish nitrate reductase activity, though not affecting root uptake of nitrate.

Differences in salinity tolerance response between two populations of *Typha domingensis* have been reported in Australia by von Oertzen and Finlayson (1984). Using seedlings, the authors found an increase in tissue water content (succulence) in the less salt-tolerant ecotype. Community structure in intertidal marsh plant communities is affected profoundly by interstitial water salinity in the soil (Ewing 1983). Ecological studies such as the latter are useful in selecting species for potential application in water treatment.

2.4.3 Temperature

Plant responses to thermal stress, as in water cooling ponds, appear to be related to two main factors. At sub-lethal temperatures there may be an increase in plant production, and possibly a decrease in the rhizome nutrient reserves. At higher temperatures, plants typically exhibit reduced size and eventual elimination, due possibly to the exhaustion of rhizome carbohydrate reserves for growth the following spring. (No reports were found linking wintertime low temperatures to adverse effects on emergent macrophytes.)

"The most common responses observed in natural populations are the enhancement of production by sublethal temperature elevations and the drastic reduction in growth rate and eventual elimination of species by larger increases in temperature" (Grace 1977, in Adriano et al. 1980).

Mention has been made previously to the effects of water temperature on growth of cattails. *Typha latifolia* has been found to tolerate temperatures of 34 to 40°C in a nuclear powerplant water cooling pond in South Carolina (Sharitz et al. 1984, Liu et al. 1978). The plants exhibited shorter leaves when grown under thermal stress, compared to plants growing at temperatures below about 30°C. *Typha domingensis* was present in the same pond, but was not found in sites warmer than 30 to 34°C. Liu et al. (1978) had previously shown that the differential thermal tolerance of the two species was associated with greater heat stability of three isoenzymes of malate dehydrogenase in *T. latifolia* than in *T. domingensis*. Overwinter marsh temperatures >8°C in Wisconsin were found to reduce carbohydrate reserves in *T. latifolia*, inhibiting growth in the subsequent spring (Bedford, pers. comm., in Adriano et al. 1980).

In a study comparing the effects of temperature on seed germination in *Typha* in North America, McNaughton (1960, in Hutchinson 1975) found that the seeds from the more southern localities (i.e. warmer climates) were able to germinate at lower temperatures than those from cooler latitudes. (No quantitative temperature details were provided in Hutchinson's review.)

Spartina alterniflora, *Spartina patens*, *Distichlis spicata* and *Juncus roemerianus* were reported to exhibit winter growth in southeastern Louisiana (Hopkinson et al. 1978).

Freezing temperatures did not cause death of immature cattail shoots overwintering in south-central Michigan (Dickerman and Wetzel 1985). The effect of a power-line right-of-way construction through a frozen *Typha latifolia* marsh was investigated in Massachusetts by Thibodeau and Nickerson (1984). No differences were found in indices of species number, diversity, evenness and richness before and after construction, indicating that heavy machinery was not harmful to the root zone when the ground was frozen. (This observation has implications with respect to mechanized harvesting in cold climates.)

2.4.4 Toxic Chemicals

Information is available on the effects of many heavy metals and some synthetic organic chemicals on the growth and metabolism of emergent macrophytes. Much of the information on heavy metal uptake is discussed in section 3.2.2.

Cattails have been identified as a genus endowed with a special resistance to metal contaminated soils in the north-eastern United States (McNaughton et al. 1974). The latter authors were unable to identify genotypic differences in *Typha latifolia* populations growing on Zn, Pb and Cd contaminated and uncontaminated soils. Both populations showed similar growth inhibition when grown on the contaminated soils (which contained 385, 37 and 16 times the content of Zn (13 ppm), Cd (2 ppm), and Pb (27 ppm), respectively, in the uncontaminated soil). Plants growing on the contaminated soils showed a significant inhibition of shoot production, a "marginally significant" inhibition of shoot production, and a "marginally significant" inhibition of root biomass yield. The study concluded the metals tolerance is probably not due to physical exclusion alone, but may involve a physiological response mechanism including cell wall precipitation. (No quantitative evidence was provided for the latter assertion.)

Dickman et al. (1983) studied the variations in aquatic vegetation of the Welland River (Ontario) as affected by discharges from the Cyanamid of Canada Ltd. chemical manufacturing plant. The exact nature of the discharge was not specified, though the report does provide suitable references. The impact zone of about 0.3 km downstream from the discharge point was completely devoid of macrophytes. The primary recovery zone of about 0.7 km below the impact zone contained sparse stands of

Typha only. The secondary and tertiary recovery zones showed the re-establishment of dense *Typha* together with *Sagittaria*, followed by the re-appearance of submerged species and filamentous algae. Cattails again stand out as species that have a generalized tolerance to conditions that are toxic to many other plants.

The response of *Phragmites communis* roots to DDT and hexachlorane was investigated in the Soviet Union by Merezhko et al. (1979). Low ambient concentrations (25 and 50 ug/L) were associated with inhibited growth of adventitious roots in water and soil, with a reduction in the total active absorbing surface (TAS), and with an increase in anion and cation exchange capacity. Increasing concentrations up to 2000 ug/L resulted in a decrease and an increase, respectively, in the TAS of roots in soil or water. Soil root area decreased by 2.5 and 1.7 times (DDT and hexachlorane, respectively), while water root area increased by 2.6 and 1.9 times. Anion exchange capacity became higher in soil roots while cation exchange capacity increased in the water roots. The results provided evidence for reconstruction of the internal mechanisms regulating mineral absorption, such that an optimum level of ion exchange capacity was maintained.

The effect of DDT and Hexachlorane on carbon assimilation in *Phragmites communis* was investigated by Shokod'ko (1979) in the Soviet Union. Five concentrations of the pesticides, up to 1000 ug/L were tested using the ^{14}C radio-isotope. A curve of percent photoassimilation as affected by the different pesticide concentrations showed two types of toxic effect. The first effect took place at the lowest concentrations (50 ug/L DDT and 25 ug/L Hexachlorane) and caused rapid drop in carbon assimilation efficiency of 25% and 35% respectively for the two chemicals. The second effect was a more gradual decrease in photoassimilation efficiency, of a further 10% for DDT and 17% for Hexachlorane at the maximum treatment levels. The first decrease was considered to be the specific toxic effect, possibly a suppression of cyclic phosphorylation, while the second was considered to be a more "general" toxic effect involving decreased photosynthetic efficiency. As the concentration of pesticide increased, the amount and transport rate of C to the root zone also increased. The results provided evidence for preferential allocation of C to the root (as opposed to the leaf) zone as a defensive reaction to severe toxicity.

2.4.5 Harvesting

Tolerance to cutting differs between species, with the softstem and hardstem bulrushes (*Scirpus acutus* and *validus*, respectively) exhibiting the best response. Regrowth of leaf and root-rhizome biomass is greater in plants cut above the water level than in those cut below water. Cutting appears to reduce the overall leaf biomass production, although higher mineral content (e.g. P) in young leaves may result in higher overall mineral removal from cropped systems.

Spangler et al. (1976) investigated the role of harvesting as a means of P removal in natural wetlands dominated by *Typha* or *Scirpus*. Each successive harvest yielded a smaller quantity of new biomass. Also, the subsequent growth rates were smaller and the percentage of shoots exhibiting regrowth decreased with the number of cuttings. The authors cite other research showing similar results for *Typha* and *Phragmites* in Czechoslovakia. Despite the lower biomass yields in comparison with plots subjected to a single end-of-season harvest, the higher P content in the younger regrowth tissue yielded a greater overall yield of P via multiple harvests. However, it was noted that species respond differently to harvesting. For example, *Scirpus acutus* and *Scirpus validus* were better adapted to cropping than were *Typha*, *Scirpus fluviatilis*, and *Sparganium eurycarpum*. Uncited studies in natural marshes were also reported to have found that harvesting at very low water levels may adversely affect the plants. The effect of cutting frequency on the removal of other minerals was not reported.

Sale and Wetzel (1983) studied the interaction of water depth and cutting in *Typha latifolia* and *T. angustifolia*. They studied plants that had been cut above the water level and those which had the cut end submerged. Oxygen could diffuse very readily to the rhizome (which was in an anoxic soil) as long as a small amount of leaf or cut stem remained above the water. More root biomass was produced in plants cut above water than below water level. The authors suggested that three below water cuts during the growing season would be sufficient to eradicate a cattail stand. Using oxygen electrodes, it was determined that oxygen in the rhizomal tissue air spaces was depleted in 8 hours if the cut end was submerged. In an attempt to determine whether the rhizomes-roots in *Typha* were physiologically adapted to anoxia, the authors sought evidence of non-toxic respiratory metabolites. Only ethanol, which is toxic, and methane, which was attributed to bacterial colonization of dead tissue, was found, leading to the conclusion that the plant is not adapted to having anoxic roots. The uncut control treatments showed the highest overall leaf production. No data were provided on tissue mineral content.

2.5 Implications for Use in Water Treatment

2.5.1 Habitat and Life History

There is no doubt that the life form and natural history of emergent aquatic macrophytes lends itself readily to their utilization in water treatment systems. The pre-adaptation to forming monodominant stands, the apparent resistance to pests, the tendency toward vegetative reproduction and genetic uniformity, and the perennial nature of the plants are all desirable characteristics in a wastewater treatment context. (Genetic uniformity may, however, cause sub-optimal performance in cases where the best available genotype has not been recognized.)

2.5.2 Productivity

The available information on productivity indicates that stands of emergent vegetation will best perform the function of removing minerals from the water during the warmer season of the year, and that prevention of flowering (i.e. preferential maintenance of vegetative growth) as well as removal of accumulated biomass would be advantageous. Optimization of mineral removal efficiency would appear to entail selecting species (singly or mixed) that will provide the most mineral removal through harvesting.

2.5.3 Mineral Uptake

Certain minerals will be more easily removed from a wetland treatment system than others, depending on where in the plant the particular elements are accumulated. Those elements which are accumulated on or in the root-rhizome may be re-released into the environment if changing physical-chemical conditions (e.g. anoxia, low pH) make them more labile. Using the wetland as a reliable mineral sink will therefore entail managing the system in such a manner as to maintain the unharvested minerals in a non-labile form. Under certain conditions (e.g. N-poor wastewaters) it would appear that macronutrient limitation may affect the potential benefit of constructed wetland systems. Treatment of low nutrient wastewaters was not discussed in the literature.

2.5.4 Tissue Mineral Content

The information available on tissue mineral content implies that the timing of harvesting may be important in terms of maximizing the removal of specific elements. Thus, the best timing for removing N may not necessarily correspond with that for P or other minerals. Nevertheless, because of the low fraction of the total mineral mass that can be captured in harvestable form, cropping would appear to be a measure which, more than having a short-term benefit, would extend the useful life of the wetland system by reducing the rate at which the system becomes saturated with elements such as P and metals.

2.5.5 Secretions into the Environment

The implications of plant secretions in a water treatment context are not yet well understood. It does appear that, since the attached microbiota benefit from the secretions, and since these microbiota may have a role to play in the treatment function, the export of organic substances from the macrophytes into the environment is probably beneficial. This is a subject area which requires considerable fundamental and applied research.

2.5.6 Decomposition Processes

The information on decomposition appears to corroborate the argument that preventing (or at least diminishing the rate of) accumulation of biomass minerals within a wetland system, by means of harvesting the standing crop, should be included as an operational factor.

2.5.7 Responses to Varying Water Depth

The information available implies that, in a well established stand, temporary water depth increases would not be detrimental, and might in fact be beneficial in terms of generating more harvestable biomass.

In a water treatment context, increased species diversity resulting from water depth management might be an asset in cases where there is limited control over hydraulic loading. Short-duration flooding or drying would be tolerated without ill effect.

2.5.8 Responses to Salt Stress

Salt stress leads to accumulation of nitrogen in the plant tissues, though there is no consistent pattern between species in terms of the organs (shoots, roots, rhizomes) in which the N accumulation takes place. Researchers infer that high Na levels somehow interfere with the activity of the nitrate reductase enzyme in the phosynthetic tissues. It remains to be demonstrated whether such an effect might be beneficially applied for increasing the removal of nitrogen from a waste water by increasing the accumulation of NO_3 in (harvestable) above-ground biomass.

2.5.9 Effect of Temperature

It appears that the use of emergent macrophytes in water treatment would be limited to temperatures between about 4° and 35°C, with the exact limits depending on the species. Wintertime reduction in the biologically mediated mineral cycling mechanisms in a wetland undoubtedly occurs. However, physical-chemical reactions in the soil, as well as the activity of psychrophilic bacteria (adapted to cold), do continue to exert an effect on nutrient cycling during the winter.

2.5.10 Effect of Toxic Chemicals

There is a need for more research on the environmental toxicology of emergent macrophytes. The indications from the sparse information available are that some species exhibit considerable tolerance to chemical toxicity. Cattail (*Typha*) and giant reed (*Phragmites*) are identified as being naturally tolerant to toxicity from heavy metals such as Zn, Pb and Cd, and synthetic organic chemicals such as DDT and

Hexachlorane, respectively. The tolerance mechanisms are thought to consist of a combination of physical exclusion and a physiological response.

Potential problems due to phytotoxicity of a given wastewater may be encountered, particularly where chemical industry effluents are involved.

2.5.11 Effect of Harvesting

Plant cutting appears to have significant implications with respect to the management of emergent vegetation for water treatment. Undesirable vegetation may be controlled by cutting below water level, while desirable vegetation must be cropped above water level. The manipulation of water level in a constructed wetland system must be carefully coordinated with harvesting schedule in order to maintain optimum conditions for treatment.

2.6 Overview of Wetland Systems for Wastewater Treatment

The literature on wetland systems for wastewater treatment is now quite extensive. International conferences on the subject have been held in Florida, Tennessee, England and other locations.

Both natural and constructed wetlands are in use, although there has been a trend of increasing use of constructed wetlands. Use of natural wetlands, through frequently proposed, often runs into opposition from the public and from natural resource agencies because the wetlands are considered part of the receiving environment and potential conflicts exist with other wetland values such as wildlife habitat, recreation, research and aesthetics.

2.6.1 Natural Wetlands

Natural wetlands were historically often the site of wastewater discharges. Much of the interest in wetlands as treatment systems arose out of the recognition that the wastewater quality often improved after passing through such wetlands (Reed 1990). Wastewaters have also been used for enhancement or restoration of wetlands. Natural wetlands are in many jurisdictions considered to be a part of the receiving environment. This has placed constraints on the use of natural wetlands for wastewater treatment. In many instances, natural wetlands have been used and continue to be proposed as functional components of effluent treatment systems. In order to maximize treatment effectiveness, substantial modification of the natural site is necessary. For example, berming and installation of inlet and outlet structures is usually desirable to control water depth and distribute flows (Kadlec 1987). In such cases the end result is a hybrid system, consisting of natural and constructed components.

Natural wetland systems are used in North America, Europe and other countries, to treat primary or secondary municipal effluents, urban runoff and mine drainage.

2.6.2 Constructed Wetlands

Most of the wetland applications for wastewater treatment involve the use of constructed wetlands designed to provide specific treatment functions. Two different design categories have been developed: surface flow and sub-surface flow systems.

The surface flow systems consist of one or more basins or channels, sometimes sealed with an impermeable liner, a layer of soil or other material in which the emergent vegetation can take root, and a relatively shallow layer of water (<0.3 m) flowing through the unit above the soil surface. Typically, a long flow path (high length to width ratio) is provided to ensure plug flow and maximize the hydraulic retention time. Wastewater flows along the surface of the bed and is treated through contact with the submerged plant parts, upper soil layer and vegetation debris and associated micro-organisms.

Sub-surface flow systems consist of a channel or trench containing soil, gravel, mining waste, or other media, for rooting of emergent vegetation, and water flowing through the soil beneath the soil surface. Combinations of media are also used. Impermeable liners are usually used to prevent exfiltration and infiltration. Depending on the design wastewater flows laterally or vertically (up or down) through the growth medium and is purified during contact with the media surfaces, vegetation root zone and associated microbiochemical conditions. Selection of a growth medium with an adequate hydraulic conductivity is critical to ensure sub-surface flow and prevent short-circuiting by surface flow. In a mature system, a steady state balance is said to be achieved between the plugging of pore space by roots and microbial growth and the regeneration of pore space through the decomposition of dead roots (Maesener 1982, cited in Wood 1990).

Examples:

Constructed wetlands with surface flow are or have been used in many North American and European municipal wastewater treatment systems. Similarly, most mine drainage systems are designed for surface flow. Sub-surface flow systems, first developed in Europe, are widely used in West Germany, England, Austria, Switzerland and other European countries, to treat screened raw sewage or primary municipal effluent. In North America, sub-surface systems are used to treat primary or secondary municipal effluents and, on an experimental basis, mine drainage and landfill leachate.

Wetland systems for wastewater treatment have been proposed or are in operation at a number of locations in western Canada. In Yukon, natural wetlands systems used in conjunction with lagoon technology have been in operation at Old Crow and Haines Junction since 1989 and 1986, respectively (Graingen, undated). These and other systems, including Faro and Destruction Bay in the Yukon and Hay River in the North West Territories, involve discharge or seepage from long term storage lagoons to natural wetlands, from which the polished effluent enters the receiving environment. Nutrient removal data were not included in the literature reviewed. Similar systems have been proposed for Teslin and Whitehorse (John Grainger, pers. comm., Yukon Department of Community and Transportation Services; Klohn Leonoff 1989). Wetlands treatment is considered by the Yukon Government to be the most cost effective method of achieving tertiary treatment for smaller communities at northern latitudes (John Grainger, personal communication).

In British Columbia, natural wetland systems are in use on a pilot basis for treatment of municipal sewage effluent and mine drainage. A pilot system at New Hazelton is intended to provide tertiary treatment of the community's sewage lagoon effluent (Tamblyn 1989). Performance data are as yet unavailable. A similar system has been proposed at 100 Mile House (Doug McIntosh, pers. comm., Waste Management Branch, Williams Lake).

Treatment of acidic mine drainage has been studied at Mount Washington on Vancouver Island (Ferguson 1986), and at Equity Silver Mine and Noranda Bell Mine in the interior of British Columbia. At Mount Washington, a bermed natural wetland has achieved copper and aluminum removals of 41% and 44%, respectively. At Equity Silver an unaltered natural wetland has achieved 87% Cu removal from acidic mine drainage (Ferguson 1986).

2.6.3 Advantages and Disadvantages

The main advantages of using natural wetlands is that they are "already there". Wetland adaptation/modification requirements and associated costs are therefore much lower than for a constructed wetland. Disadvantages include potentially adverse impacts on existing wetland functions and values through alteration of hydrologic and nutrient regimes, which can lead to changes in vegetation and, consequently, wildlife habitat and other values. The need to conserve natural wetlands for the ecological functions they provide is the basis of the protective regulatory policies that have been adopted in many countries, including Canada. The potential conflict between wastewater treatment and the natural wetland functions is minimized where wastewater flows follow the natural seasonal hydrologic pattern. Such conditions exist typically with surface mine and landfill drainage and urban runoff, and typically do not exist with municipal sewage and industrial wastewater.

The main advantage of constructed systems is greater process control than in natural wetlands. Micro-relief, water depth, flow distribution and plant species can be optimized to achieve maximum treatment. Disadvantages are related to construction costs and the post-construction lag period, which can range from one to three years, before the biological system matures and reaches a steady state condition. Constructed wetland systems usually provide additional incidental environmental benefits, such as wildlife habitat, where none existed before (Sather 1989). In this context, constructed systems also can contribute to reversing the historical trend of wetland loss.

2.6.4 Contaminant Removal Mechanisms

Wastewater treatment in wetland systems involves a combination of physical, chemical and biological mechanisms. Each of these mechanisms affects different types of contaminants to varying degrees. The primary physical mechanisms can include sedimentation and filtration of particulate matter, and adsorption. The main chemical mechanisms include precipitation of certain dissolved minerals, adsorption and complexing of certain minerals and organic compounds, and decomposition by sunlight, oxidation and reduction. Biological mechanisms include assimilation, metabolic transformations of wastewater by microbial and plant populations, and natural die-off of pathogens in an unfavourable environment. Table 2.6.4-1, adapted from Stowell et al. (1980) summarizes the contaminant removal mechanisms in wetlands.

TABLE 2.6.4-1

CONTAMINANT REMOVAL MECHANISMS IN AQUATIC SYSTEMS EMPLOYING PLANTS AND ANIMALS

MECHANISM	CONTAMINANT AFFECTED[a]	DESCRIPTION
PHYSICAL		
Sedimentation	P - Settleable solids S - Colloidal solids I - BOD, nitrogen, phosphorus, heavy metals, refractory organics, bacteria and virus	Gravity settling solids (and constituent contaminants) in pond/marsh settings.
Filtration	S - Settleable solids, colloidal solids	Particulates filtered mechanically as water passes through substrate, root masses, or fish.
Adsorption	S - Settleable solids, colloidal solids	Interparticle attractive force (van der Waals force).
CHEMICAL		
Precipitation	P - Phosphorus, heavy metals	Formation of or coprecipitation with insoluble compounds.
Adsorption	P - Phosphorus, heavy metals S - Refractory organics	Adsorption on substrate and plant surface.
Decomposition	P - Refractory organics	Decomposition or alteration of less stable compounds by phenomena such as UV irradiation, oxidation, and reduction.
BIOLOGICAL		
Microbial metabolism[b]	P - Colloidal solids, BOD, nitrogen, refractory organic, heavy metals	Removal of colloidal solids and soluble organics by suspended, benthic, and plant-supported bacteria. Bacterial nitrification/denitrification. Microbially mediated oxidation of metals.
Plant metabolism[b]	S - Refractory organics, bacteria, and virus	Uptake and metabolism of organics by plants. Root excretions may be toxic to organisms of enteric origin.
Plant absorption	S - Nitrogen, phosphorus, heavy metals, refractory organics	Under proper conditions, significant quantities of these contaminants will be taken up by plants.
Natural dieoff	P - Bacteria and virus	Natural decay of organisms in an unfavorable environment.

Source: Stowell et al. 1980

[a] P = primary effect
S = secondary effect
I = incidental effect (effect occurring incidental to removal of another contaminant)

[b] Metabolism includes both biosynthesis and catabolic reactions.

2.7 Plant Species Selection

The plant species composition in a natural wetland system receiving wastewater can change in response to the altered hydraulic regime and water quality (Kadlec 1987). In this sense, a natural wetland can "self select" the species that are best adapted to the wastewater addition.

Selection of plant species for constructed wetland systems has been based on a number of factors, including tolerance of wastewater quality, depth of root zone, ease of transplanting or seeding and vigorous growth. As with natural wetlands, there is an element of "self design", in that, subject to the availability of a variety of species, those that are best adapted to the prevailing hydrological, chemical and vegetation management (i.e. harvesting) regime will predominate over time. Useful information on the plant species selection is provided among others by Stephenson et al. (1985), Hammer (1992), and Warburton et al. (1985).

2.8 Constructed Wetland Design Methods

Experience is available primarily with municipal effluents and acid mine drainage. The wastewater constituents of concern have been biochemical oxygen demand (BOD) and nutrients, and pH and metals, respectively. The primary design basis for municipal effluents has been hydraulic loading, whereas metal mass loadings have been used for mine drainage. Design equations based on reaction kinetics are also available for surface and sub-surface flow wetlands, but are limited primarily to municipal wastewater, with an emphasis on BOD (Watson et al. 1989).

2.8.1 Design Based on Empirical Data

Municipal Wastewater

An extensive comparison of hydraulic loading rates of 31 surface and 13 sub-surface flow wetlands treating municipal effluents in North America has been provided by Watson et al. (1987). Table 2.8.1-1 shows the recommended hydraulic loading ranges for preliminary design to achieve secondary or advanced treatment objectives with both types of systems. Advanced treatment, based on the survey, requires 1.9 to 3.1 cm/day, (190 to 310 $m^2/m^3/d$) for a surface flow system, and 3.1 to 4.7 cm/day (310-470 $m^2/m^3/d$) for a sub-surface system.

Acid Mine Drainage

Design guidelines available for treatment of acid mine drainage have been developed in the United States (Girts and Kleinmann 1983; Brodie et al. 1988). These have been

TABLE 2.8.1-1

RECOMMENDED HYDRAULIC LOADING RATES FOR PRELIMINARY DESIGN OF CONSTRUCTED WETLANDS FOR TREATING MUNICIPAL WASTEWATER

SYSTEM USE	TREATMENT OBJECTIVES							
	SECONDARY TREATMENT				ADVANCED TREATMENT/MULTIPLE OBJECTIVES			
	SURFACE FLOW		SUBSURFACE FLOW		SURFACE FLOW		SUBSURFACE FLOW	
	cm/day	acres/mgd	cm/day	acres/mgd	cm/day	acres/mgd	cm/day	acres/mgd
Basic Treatment	a	a	2.3 to 6.2	40 to 15	a	a	≥3.1	≥20
Secondary Treatment	1.2 to 4.7	75 to 20	4.7 to 18.7	20 to 5	≥1.9	≥50	≥4.7	≥20
Polishing Treatment	1.9 to 9.4	50 to 10	4.7 to 18.7	20 to 5	≥3.1	≥30	≥4.7	≥20

Source: Watson et al. 1989.

[a] This use has not yet been demonstrated. Surface flow systems constructed to date are preceded by at least primary treatment units (septic tanks, clarifiers, lagoons, etc.).

based on surveys of 20 and 11 wetlands, respectively, constructed at mines in that country. Because metal concentrations in acid drainage vary considerably, design guidelines have been based on mass loadings of specific metals, with iron and manganese being the priority parameters. Loading rates of 2.0 m^2/mg Fe/min and 7.0 m^2/mg Mn/min have been recommended for waters with a pH below 5.5, while loading rates of 0.75 m^2/mg Fe/min and 2.0 m^2/mg Mn/min are recommended if the pH is greater than 5.5. Guidelines for other metals are not available.

Other Considerations

Additional factors which can be used to guide the selection of an appropriate design loading rate are quoted below from recommendations by Watson et al. (1989).

1. Treatment Objectives. Compliance with permit limits is a standard consideration. Stringent limits require lower loading rates. Lower loading rates may also be needed to meet ancillary objectives, e.g., wildlife enhancement or aesthetics.

2. System Use. Constructed wetlands can be used to provide basic (primary and secondary) treatment following pretreatment (screening/comminution); secondary/advanced treatment following primary treatment (lagoons/septic tanks/clarifiers); or polishing treatment following any type of existing treatment facility. The relative trend in loading rates is to increase as the level of use progresses from basic to polishing treatment.

3. System Type. Surface flow wetlands are considered less efficient on an area basis than subsurface systems because of smaller quantities of attached micro-organisms available to process the wastes. The quantity of attached microorganisms is a function of the surface area provided by the system. Subsurface flow systems provide much more attachment surface on an area basis than surface flow systems (assuming clogging does not result in surface flow), allowing higher loading rates.

4. System Configuration. Use of multiple cells in series, parallel, or combinations increases the potential for optimizing treatment processes, minimizing treatment area, and maximizing loading rates. Cell types can also be varied, and recirculation can further improve performance.

5. Safety Factors. Constructed wetlands technology is still under development. Many answers are needed before designs can be optimized and performance levels firmly established. Consequently, users may choose to design conservatively with low loading rates to reduce risks of future upgrades. Alternately, a principal advantage of the technology is the ease of expansion as needed if this option is incorporated into the original planning and siting.

This strategy might use higher initial loading rates, with upgrades added as necessary based on actual performance and future needs (Watson et al. 1989).

2.8.2 Design Based on Reaction Kinetics

Design equations are available for surface and subsurface flow wetlands treating municipal wastewater. These equations are based on the assumption that constructed wetlands are attached-growth biological reactors and their performance can be described with first order, plug-flow, steady state reaction kinetics. Theoretically, removal of organic matter (i.e. removal of BOD, COD, TOC), nitrification, denitrification, disinfection and adsorption can be predicted using first-order kinetics (Metcalf and Eddy, Inc. 1979). However, in reality plug flow and steady state conditions seldom occur in constructed wetlands.

Development of kinetic design equations requires the experimental determination of the reaction rate and constants, which depend on the characteristics of the treatment systems. Rates for constructed wetland systems have been reported only for BOD. Experience with overland flow and trickling filter systems may also be applied to constructed wetland design (Reed et al. 1988).

Reed (1990) recommends that caution should be used in the application of kinetic relationships since, to date, these are based on a limited data base; moreover he states "a pilot test is strongly recommended for most projects". Kadlec (1989) provides guidance and describes possible errors resulting from neglecting other phenomena that occur in wetlands.

It is generally agreed that the reliable application of reaction kinetics to the design of constructed wetland systems is limited by the following factors (Watson et al. 1989; Reed 1990; Kadlec 1989):

- limited data base, especially for parameters other than BOD and wastewaters other than municipal sewage;
- limited hydrological and related data on which to base equations defining the hydraulic flow regime and residence time; and
- changing physical and bio-chemical characteristics over time (since treatment effectiveness normally increases and stabilizes as the wetland ages).

A summary of kinetics-based design approaches for surface and sub-surface flow constructed wetlands is provided in **Appendix A**.

2.9 Wastewater Types

Reports are available on wetlands use for treatment of the following wastewater types, ranked in descending order:

- Municipal effluents
- Acid mine drainage
- Urban runoff and stormwater
- Landfill leachate (Staubitz et al. 1988; Birkbeck et al. 1990)
- Agricultural and food industry effluents
- Petrochemical industry effluent
- Pulp mill effluent
- Photochemical laboratory effluent
- Non-acid mine drainage

2.10 Treatment Performance

Contaminant removal by wetlands systems has been documented for a number of municipal, mining and other wastewaters in North America, Europe and, to a lesser extent, Australia and Africa. A listing of constructed wetlands performance for small municipal systems and acid mine drainage has been compiled by Watson et al. (1989). Selected examples of nutrient and metals removal in constructed wetlands in temperate climates, from a number of wastewater types are shown in Tables 2.10-1 through 2.10-5.

2.11 Operation and Maintenance

Operation and maintenance (O&M) needs vary greatly among wetland treatment systems, depending on whether the wetland is natural or constructed, surface or subsurface flow, and on the initial design. Systems constructed to date range from those designed for "average" conditions to those designed to accommodate extreme conditions expected during the system's life span. An overview of wetland operations optimization is provided by Girts and Knight (1989). They conclude that "designs that adjust for periods of disturbance through operations changes can extend the life and increase the efficiency of new systems" and "from experience, reliance on system resiliency is often more beneficial than human intervention."

Natural Wetlands

Natural wetlands receiving wastewater perform their treatment functions passively and, as such, are not "operated" as are constructed systems. The operational emphasis in natural wetlands is to ensure that the wastewater is entering the wetland at the desired location(s) and in the desired amounts; and is residing in the system for the desired

TABLE 2.10-1

AMMONIA NITROGEN REMOVAL PERFORMANCE OF WETLAND SYSTEMS TREATING MUNICIPAL WASTEWATER

LOCATION	PERIOD	SYSTEM TYPE	HYDRAULIC LOADING (cm/d)	INFLUENT (mg/l)	EFFLUENT (mg/l)	REMOVAL EFFICIENCY (%)
Listowell, Ontario (Herskowitz 1986)	9/80-8/84	Surface				
		System 3	1.4	7.2	3.8	47
		System 4	1.4	8.6	6.1	29
Brookhaven NL, New York (Small 1978)	8/75-8/76	Surface Marsh/Pond	3.35	8.4	3.5	58
Iselin, PA (Watson et al. 1987)	3/83-9/85	Subsurface Gravel				
		Marsh/Pond/Meadow	1.47	30	3.3	83
		Marsh	5.28	30	13	56
		Meadow	10.57	5.2	3.3	36
Gravesend, England (Cooper & Hobson 1989)	4/86-1/88	Subsurface gravel				
		Bed 1	8.16	43	37	14
		Bed 2	8.16	43	36	16
		Bed 3	8.16	43	36	16
Castleroe, England (Cooper & Hobson 1989)	4/87-1/88	Subsurface gravel				
		Cell 1	4.34	19.1	14.5	24
		Cell 2	4.34	19.1	17.3	9
		Subsurface soil				
		Cell 1	4.34	19.1	13.9	27
		Cell 2	4.34	19.1	18.2	5
Blusher Burn, England (Cooper & Hobson 1989)	5/87-3/88	Subsurface				
		Fine Fly Ash	10.76	27	24	11
		Coarse Fly Ash	6.24	27	20	26
		Unclassified gravel	9.93	27	20	26
		Gravel	10.09	27	22	19
Ringsted, Denmark (Jacobsen 1985)	9/84-10/84	Subsurface				
		Gravel	5.70	34	15	56
		Clay	1.71	34	15.3	55
Mpophomeni, South Africa (Wood and Hensman 1989)	Not Reported	Subsurface	5.24	2.8	1.2	57

TABLE 2.10-2

TOTAL NITROGEN REMOVAL PERFORMANCE OF WETLAND SYSTEMS TREATING MUNICIPAL WASTEWATER

LOCATION	PERIOD	SYSTEM TYPE	HYDRAULIC LOADING (cm/d)	INFLUENT (mg/l)	EFFLUENT (mg/l)	REMOVAL EFFICIENCY (%)
Listowel, Ontario (Herskowitz 1987)	9/80-8/84	Surface				
		System 3	1.4	12.3	6.3	49
		System 4	1.4	19.1	8.9	53
Brookhaven NL, New York (Small 1978)	8/75-8/76	Surface Marsh/Pond	3.35	19.7	6.8	65
Ringsted, Denmark (Jacobsen 1985)	9/84-10/84	Subsurface				
		Gravel	5.70	48	29.6	38
		Clay	1.71	48	18.8	61
Lunderskov, Denmark	8/84-8/85	Natural wetland	(200)*	14	6	53
Kalo, Denmark	3/85-8/85	Subsurface	(300)*	45	40	10
Ingstrup, Denmark (Brix 1987)	6/84-9/85	Subsurface	(5)*	112	12	88
Mannersdorf, Austria (Haberl and Perfler 1989)	10/87	Subsurface				
		raw sewage	6.1	28.9	18	38
		primary sewage	5.9	37.2	11.5	69
		secondary sewage	5.9	22.0	6.0	72

* = population equivalent

TABLE 2.10-3

TOTAL PHOSPHORUS REMOVAL PERFORMANCE OF WETLAND SYSTEMS TREATING MUNICIPAL WASTEWATER

LOCATION	PERIOD	SYSTEM TYPE	HYDRAULIC LOADING (cm/d)	INFLUENT (mg/l)	EFFLUENT (mg/l)	REMOVAL EFFICIENCY (%)
Listowell, Ontario (Herskowitz 1987)	9/80-8/84	Surface				
		System 3	1.40	1	0.5	50
		System 4	1.40	3.2	0.6	81
Brookhaven NL, New York (Small 1978)	8/75-8/76	Surface Marsh/Pond	3.35	7.2	2.1	71
Iselin, PA (Watson et al. 1987)	3/83-9/85	Subsurface sand/gravel				
		Marsh/pond/meadows	1.47	13	2.6	80
		Marsh	5.28	13	4.2	69
		Meadow	10.57	3.4	2.6	23
Gravesend, England (Cooper and Hobson 1987)	4/86-1/88	Subsurface Gravel				
		Bed 1	8.16	12.6	7.2	42
		Bed 2	8.16	12.6	7.5	40
		Bed 3	8.16	12.6	5.0	60
Castleroe, England (Cooper and Hobson 1987)	4/87-1/88	Subsurface Gravel				
		Cell 1	4.34	5.0	4.0	20
		Cell 2	4.34	5.0	4.0	20
		Subsurface Soil				
		Cell 1	4.34	5.0	2.9	50
		Cell 2	4.34	5.0	5.6	12
Bluther Burn, England (Cooper and Hobson 1988)	5/89-3/88	Subsurface				
		Fine Fly Ash	10.76	10.49	3.64	65
		Coarse Fly Ash	6.24	10.49	1.71	84
		Unclassified gravel	9.93	10.49	0.93	91
		Gravel	10.09	10.49	3.14	70
Ringsted, Denmark (Jacobsen 1985)	9/84-10/84	Subsurface				
		Gravel	5.70	15	9.6	56
		Clay	1.71	15	6.0	60
Lunderskov, Denmark	8/84-8/85	Natural Wetland	(200)*	4.2	2.4	45
Kalo, Denmark	3/85-8/85	Subsurface	(300)*	9.3	8.8	11
Imptrump, Denmark (Brix 1987)	6/84-9/85	Subsurface	(5)*	51	3.2	94
Mpophomeni, South Africa (Wood and Hentman 1988)	Not Reported	Subsurface (orthophosphate-P)	5.24	7.0	0.87	87.7
Mannersdorf, Austria (Haberl and Perfler 1988)	10/87	Subsurface				
		Raw sewage	6.1	5.4	1.8	69
		Primary Sewage	5.9	7.3	1.2	84
		Secondary Sewage	5.9	4.9	1.1	76
Cobalt, Ontario (Miller 1989)	7/83-7/84	Surface	1.9	1.5	0.7	57

* = population equivalent

TABLE 2.10-4

METALS REMOVAL PERFORMANCE OF WETLAND SYSTEMS TREATING ACID MINE DRAINAGE

LOCATION	SYSTEM TYPE	HYDRAULIC LOADING (cm/d)	INFLUENT (mg/l)			EFFLUENT (mg/l)			REMOVAL EFFICIENCY (%)	
			pH	Fe	Mn	pH	Fe	Mn	Fe	Mn
TVA: (Watson et al. 1989)	Surface									
King 006		21.2	6.0	170	4.9	2.9	17.0	3.8	96	22
WC 018		5.1	5.6	150	6.8	3.9	6.3	6.4	96	59
Imp 4		3.02	4.9	135	24	5.0	2.3	3.5	90	85
Imp 1		1.52	6.0	32.8	9.6	6.5	0.7	2.0	99	93
Col 013		15.53	5.7	0.7	7.0	6.7	0.7	3.0	0	57
Others: (average of 20 sites) (Kleinmann and Girts 1987)		14.13	4.9	33	26	6.0	1.2	15	96	42

TABLE 2.10-5

CONTAMINANT REMOVAL PERFORMANCE OF CONSTRUCTED WETLANDS TREATING SELECTED WASTEWATER

WASTEWATER	CONTAMINANT REMOVAL EFFICIENCY (%)										
	TSS	BOD	COD	NH_3-N	P	Org-N	S^-	Cr^{+6}	Pb	Phenols	Oil/Grease
Oil Refinery (Litchfield & Shatz 1989)	90	84.4	70.9	84.6			100	100		95	95.3
Pulp Mill, Year 3 (Thut 1989)	46	32		70	19	35					
Urban Stormwater (Meiorin 1989)	64	-35		10	48			68	88		

minimum period to effect treatment (Kadlec 1989). Thus most O&M tasks in natural wetland treatment systems are related to monitoring influent quantity and water quality and effluent quality.

Constructed Wetlands

Process control is more important in constructed because treatment performance depends on a number of factors such as hydraulic and/or contaminant loading, water level, and the condition of the microbial and vegetation communities. Many of these factors vary seasonally and can be controlled to optimize treatment efficiency. Usually, constructed wetlands are designed for a range of expected flows. Consequently, control of hydraulic loading is not required, except possibly to protect the system from failures due to up-stream accidental spills or damage by extreme high or low flows.

Up-stream Toxic Spills

Protection from ecosystem upset or potential damage due to upstream toxic spills can be provided if the system design allows for operational options such as up-stream storage with or without contingency treatment, influent dilution (with an alternative water source or by recirculation of wetland effluent), or diversion to an alternative storage/treatment location.

Flow Control

Wetland systems treating relatively uniform flows, such as municipal or many industrial effluents are usually not exposed to extreme variations in hydraulic loading. By contrast, systems treating drainage from mines, land fills and urban areas must withstand flood and drought extremes. Avoidance of channelling or scouring damage during flood flows requires the system design to provide such operational options as temporary baffling, increased water depth, up-stream retention, and/or flow diversion. Protection of the vegetation and microorganisms from heat stress or dehydration due to low flow requires the ability to provide water storage within the wetland by increasing water depth, provide an alternative water source, divert flows to affected wetland areas, or to recirculate wetland effluent.

Other Operational Needs

Operational needs will also vary with the type of wastewater being treated, but will generally include one or more of the following tasks:

- monitoring of hydraulic loading and discharge, including inspection of related plumbing, pumps and weirs;

- monitoring of influent and effluent water quality;
- monitoring of vegetation and berms to detect pest outbreaks, nuisance burrows or other disturbances;
- seasonal regulation of water levels to:
    - accommodate low or high flows;
    - prevent surface flow over winter ice (Miller 1989);
    - increase rooting depth and control weeds in subsurface flow systems (Cooper and Hobson 1987) or facilitate rapid vegetation regrowth in the spring and harvesting of vegetation in surface flow systems (Girts and Knight 1989); and
    - facilitate sediment aeration and mineralization (desirable for organic matter and nitrogen removal; not desirable for phosphorus removal);
- redirection of flow around the wetland in response to flood flows, or to facilitate plant harvesting or other maintenance;
- recirculation of wetland effluent if necessary to irrigate the wetland or to increase treatment effectiveness; and
- harvesting of vegetation to remove nutrients and metals.

Vegetation Harvesting

Experience with vegetation harvesting is limited to date. In theory, removal of the above-ground plant biomass eliminates nutrients and metals and can prevent seasonal export of minerals due to flushing of plant fragments and decomposition products. However, harvesting is not always desirable since the leaf litter serves as a support substrate for microorganisms, and decomposing plant matter contributes to maintenance of reducing conditions, and is a source of carbon for denitrification. In addition, certain species are not well adapted to the stress induced by cutting.

In situations where harvesting is desirable, the process is optimized by cutting the plants while the mineral content of the above-ground portion is highest. In temperate latitudes, harvesting is best carried out in the late growing season, before the minerals are translocated to the roots for storage during winter dormancy.

Pest Control

Pest control has been required at a number of sites. Damage can occur due to insects, which can damage extensive areas of vegetation, and large rodents such as muskrat and beaver, which can burrow through berms and gnaw through plastic pipes (Norecol 1992). In addition, mosquitoes have also been identified as a public health concern at some sites (Stowell et al. 1985). Control of the cattail armyworm (Simyra henrici, a moth larva) at a wetland in Tennessee required helicopter application of the insecticide Lorsban (Snoddy et al. 1989).

2.12 Selected Case Studies from Western Canada

2.12.1 Domestic Sewage

Natural wetland systems have been used for community wastewater treatment in Western Canada for several decades. Most of these systems are located in the Yukon Territory, where systems exist at Old Crow, Destruction Bay and Faro, and systems are proposed at Teslin, Haines Junction and Whitehorse (Grainger, undated). Similar systems exist or are proposed for Hay River in the North West Territories and at Hundred Mile House, and New Hazelton, British Columbia. Most if not all of these wetlands receive primary or secondary effluent, which is discharged to the wetland once or twice per year only, during the growing season. The treatment function of these wetlands is to provide nutrient removal prior to discharge to the receiving river or lake. A natural bog near the community of New Hazelton has been partially bermed to provide tertiary treatment of the community's sewage which is treated in a lagoon system (Tamblyn 1989). The bermed area is approximately 32.5 ha and receives an estimated 410 m^3/d (8.8 mm/week) of lagoon effluent. In a study of the wetland treatment system, problems were encountered with seepage of effluent through the berm and subsidence of the berm fill into the wetland peat, and concerns were expressed with respect to environmental impacts on the bog (Tamblyn 1989). Unfortunately, performance data were not provided in the latter author's report.

2.12.2 Mine Drainage

Acid mine drainage is being treated experimentally at three locations in British Columbia: Mount Washington, Equity Silver and Bell Mine. The Mount Washington system, which was operated by Environment Canada, is no longer being monitored (K. Ferguson, Mining and Metallurgy Division, pers. comm.). The natural wetland system at Equity Silver Mine is also no longer being monitored (K. Ferguson, pers. comm.). The system at Bell Mine has been in operation for one growing season only, and results to date are limited (L. Gormely, pers. comm.). At Mount Washington, installation of a berm to increase the residence time of the acidic drainage in a natural wetland dominated by cottongrass increased the removal of Cu and Al from 33% and

25% before berming, to 41% and 44%, respectively, after berming. Corresponding final effluent concentrations after berming were 5.0 mgCu/L and 4.7 mgAl/L. At Equity Silver Mine, Cu concentration in acidic drainage passing through an un-altered natural wetland declined from 0.029 mg/L upstream to 0.004 mg/L (87% removal) below the wetland (Ferguson 1986). At Bell Mine, a pilot scale constructed wetland system has been constructed to investigate and demonstrate the efficiency of metals removal from contaminated seepage (Gallinger et al. 1991). Performance data are not yet available, as construction and transplanting of vegetation took place in 1990 and the macrophyte community was becoming established during the summer of 1991. However, microbiological tests have confirmed the presence of sulphate reducing bacteria in the substrates of the constructed wetland cells.

The experimental wetland system at Quinsam Mine on Vancouver Island, British Columbia, which is the subject of this report was monitored between August 1988 and March 1991. This system used a simulated wastewater to investigate the use of wetlands to remove nitrate originating from explosives residues at coal mines. Information on this system is presented in the remaining sections of this report.

2.13 Research Needs

Sufficient information appears to be available to design wetland systems that remove significant quantities of pollutants from municipal and mining wastewaters. However, there is insufficient information to optimize the design and operation or to assure process reliability with respect to a given pollutant (Watson et al., 1989).

The empirical data base to design wetland systems for municipal wastewater treatment are well underway, and preliminary design equations have been developed and are being disseminated in North American for BOD, ammonia and total nitrogen (Reed et al. 1990). Since many reactions that are responsible for contaminant removal in wetlands are thought to follow first order kinetics, it may be possible to establish a mathematical design basis for a number of other pollutants (Watson et al. 1989). However, some researchers have concluded that the complex treatment processes occurring in wetland may not follow first-order removal kinetics (Bavor et al. 1989).

To achieve the goal of rational design, improved predictive models, based on first-order or more complex kinetics, are required. Research is therefore necessary to determine the following important model components:

- reaction rate constants for a number of pollutants (e.g. nitrate, ammonia, dissolved and bio-available phosphorus, and dissolved metals, or other target pollutants) on a wastewater specific basis;

- temperature dependency coefficients for surface and subsurface wetland types, by vegetation species assemblage and by region;
- modifiers such as site-specific porosity functions, evapotranspiration coefficients, infiltration and exfiltration rates that establish the actual, as opposed to theoretical, hydraulic residence time in any given locality; and
- effects of wetland aging on treatment performance.

Given the complexity of, and regional variability among, wetland systems, it is likely that site-specific or regional factors will need to be taken into account in future wetland designs. Identification of the significant factors is still incomplete and will require funding commitments to continue long term monitoring of existing wetland systems.

WORK PROGRAM (METHODS)

3.1 Project Description

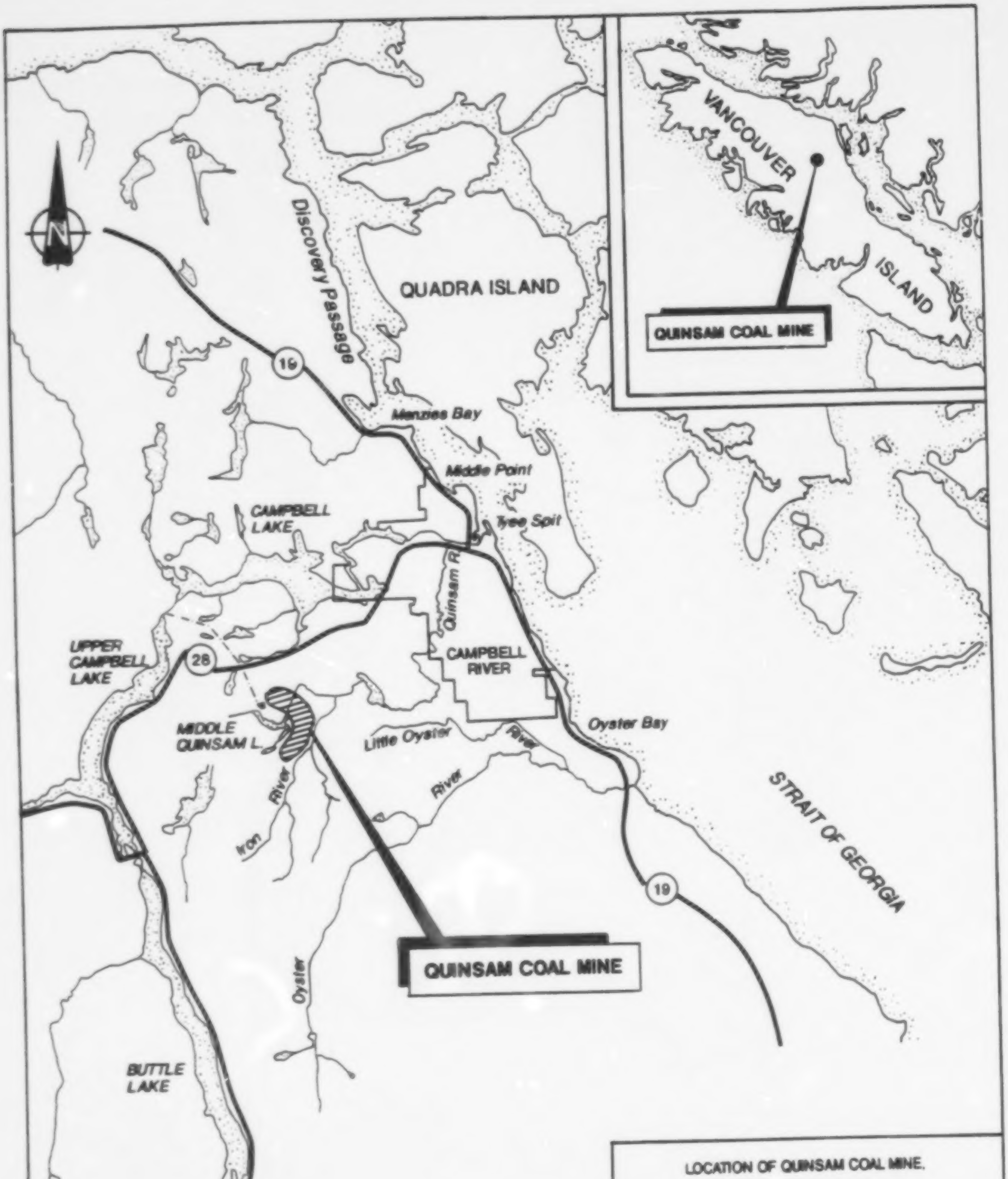
3.1.1 Location

The project is located at the Quinsam Coal Ltd. surface mine on Vancouver Island near Campbell River, British Columbia (Figure 3.1-1). The project site lies within a natural wetland (4 ha) at approximately 290 m above sea level (Plates 1 and 2, Appendix C). The natural wetland receives the effluent from the mine's main settling pond, treating drainage from all disturbed areas of the mine, including the open pit, waste rock dumps and coal processing facilities. The natural wetland drains into another wetland adjacent to the Quinsam River and Middle Quinsam Lake (Figure 3.1-2). The Quinsam river system supports a significant sport fishery and a salmon hatchery. Middle Quinsam lake is considered important fish habitat because coho salmon from the hatchery are transplanted to the lake for rearing. The study site at Quinsam Coal mine was selected because it represented a mature wetland ecosystem receiving drainage from an operating coal mine.

3.1.2 Wetland Design

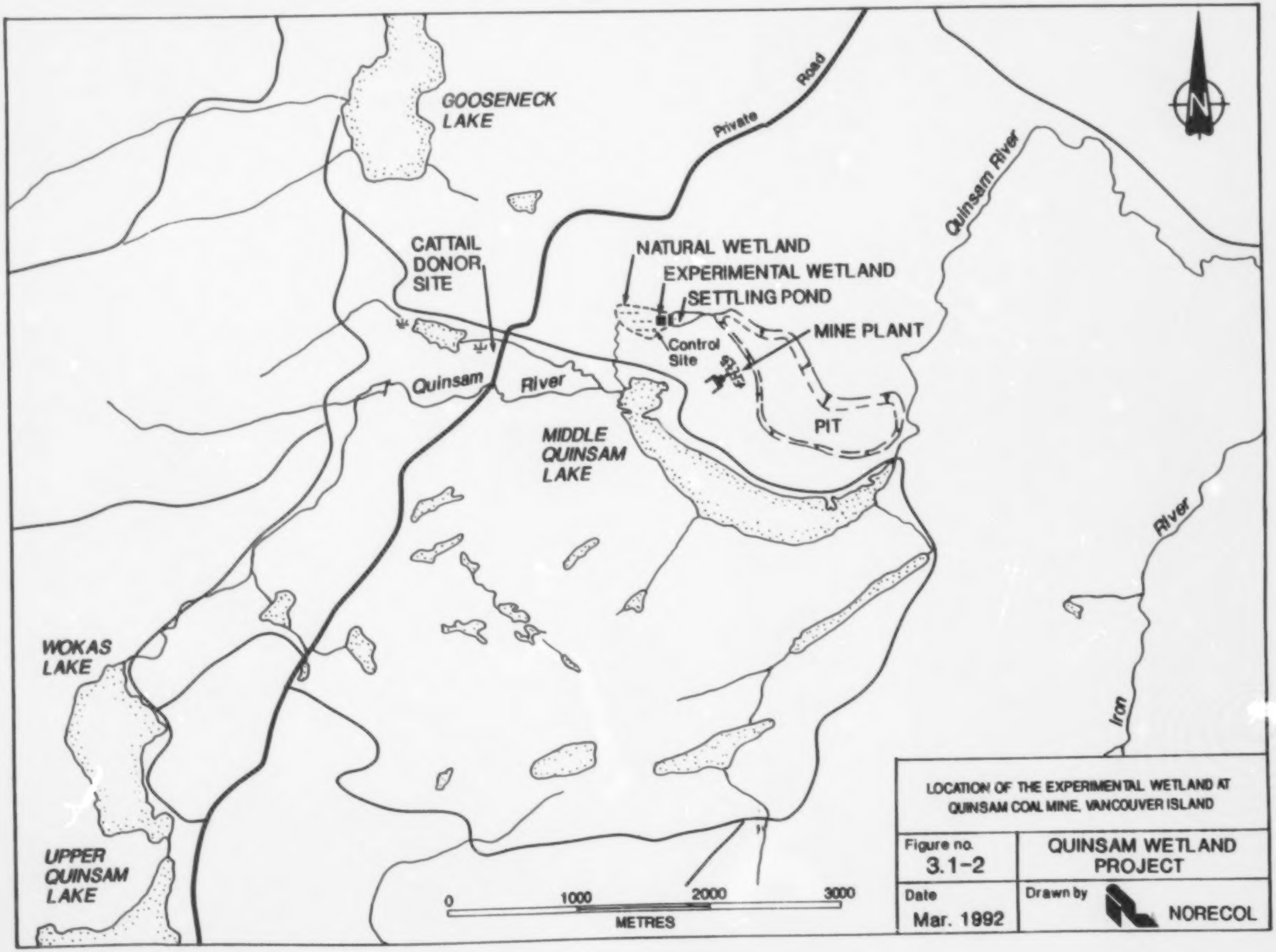
An 800 m^2 section of the natural wetland below the settling pond (Figure 3.1-3) was enclosed with a plastic-lined earthen berm (Figure 3.1-4) to create a hydrologically isolated experimental system. The existing vegetation was dominated by woody species (sweetgale, *Myrica gale*, and, to a lesser extent, hardhack, *Spiraea douglasii*). These species shade out the sedges (*Carex* sp.) which are better adapted to continuously flooded or marsh-like conditions and hence are more desirable for wastewater treatment. Woody shrubs within the enclosure were therefore cleared to favour the growth of sedges. Cattail (*Typha* sp.), which though common in the area did not occur naturally at this site, was also interplanted to increase the diversity of marsh species (Section 3.1.3) (See also Plates 1, 2 and 3, Appendix C).

A ridge of high ground within the enclosure divided the experimental wetland into two distinct basins (Figure 3.1-3). Baffles made of logs were installed in each basin to ensure even flow distribution. During Year 2, the log baffles were upgraded with plywood.


N
VANCOUVER
ISLAND
QUINSAM COAL MINE
Discovery Passage
QUADRA ISLAND
19
Menzies Bay
Middle Point
CAMPBELL LAKE
Tyee Spit
Quinsam R
UPPER CAMPBELL LAKE
28
CAMPBELL RIVER
MIDDLE QUINSAM L.
Little Oyster
River
Oyster Bay
Iron
River
River
STRAIT OF GEORGIA
19
QUINSAM COAL MINE
Oyster
BUTTLE LAKE

LOCATION OF QUINSAM COAL MINE, VANCOUVER ISLAND

Figure no. 3.1-1	QUINSAM WETLAND PROJECT
Date Mar. 1992	Drawn by NORECOL


GOOSENECK LAKE
Private Road
Quinsam River
CATTAIL DONOR SITE
NATURAL WETLAND
EXPERIMENTAL WETLAND
SETTLING POND
MINE PLANT
Control Site
Quinsam River
PIT
MIDDLE QUINSAM LAKE
River
Iron
WOKAS LAKE
UPPER QUINSAM LAKE
0
1000
2000
3000
METRES
N

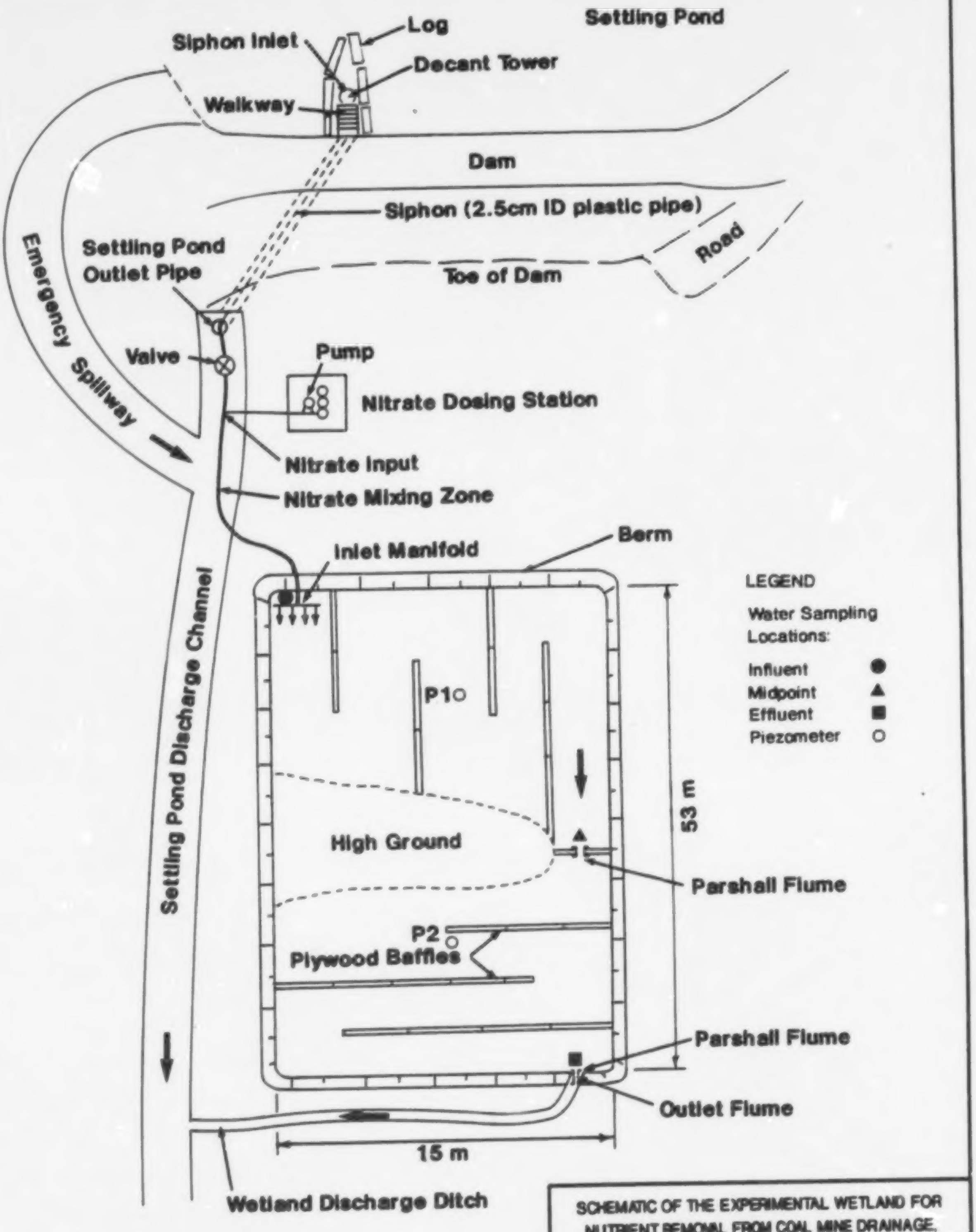
LOCATION OF THE EXPERIMENTAL WETLAND AT QUINSAM COAL MINE, VANCOUVER ISLAND

Figure no. 3.1-2

QUINSAM WETLAND PROJECT

Date Mar. 1992

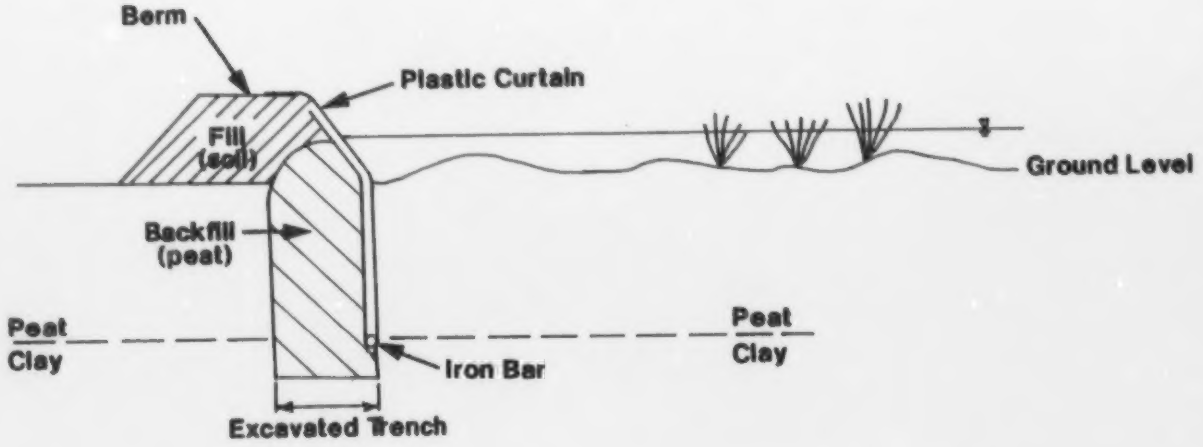
Drawn by NORECOL


Log
Settling Pond
Siphon Inlet
Decant Tower
Walkway
Dam
Siphon (2.5cm ID plastic pipe)
Road
Toe of Dam
Settling Pond Outlet Pipe
Emergency Spillway
Valve
Pump
Nitrate Dosing Station
Nitrate Input
Nitrate Mixing Zone
Berm
Inlet Manifold
LEGEND
Water Sampling Locations:
Influent ●
Midpoint ▲
Effluent ■
Piezometer ○
Settling Pond Discharge Channel
P1
53 m
High Ground
Parshall Flume
P2
Plywood Baffles
Parshall Flume
Outlet Flume
15 m
Wetland Discharge Ditch

NOT TO SCALE

SCHEMATIC OF THE EXPERIMENTAL WETLAND FOR NUTRIENT REMOVAL FROM COAL MINE DRAINAGE, QUINSAM COAL MINE, VANCOUVER ISLAND

Figure no. 3.1-3	QUINSAM WETLAND PROJECT
Date Mar. 1992	Drawn by NORECOL


Berm
Plastic Curtain
Fill (soil)
Ground Level
Backfill (peat)
Peat
Clay
Peat
Clay
Iron Bar
Excavated Trench

DETAIL OF EXPERIMENTAL WETLAND BERM
CONSTRUCTION, QUINSAM COAL MINE,
VANCOUVER ISLAND

Figure no.
3.1-4

QUINSAM WETLAND
PROJECT

Date
Mar. 1992

Drawn by
NORECOL

3.1.3 Cattail Transplanting

To accelerate the creation of a marsh community within the site, cattail (*Typha* sp.) were transplanted in mid July from a nearby natural marsh (Figure 3.1-2). Approximately 350 propagules, consisting of rhizomes of greater than 20 cm length bearing a shoot (pruned to approximately 20-30 cm above the rhizome), were collected and planted at approximately 1 m spacing and approximately 20 cm deep within the peat substrate. Placement of the transplants was concentrated where woody shrubs had previously been dominant. Additional cattail rhizomes were transplanted in April 1989 in the few small areas where previous transplanting success had been limited (Norecol 1989, 1990). Mature seed heads were also collected at this time and seeds were dispersed manually throughout the wetland.

3.1.4 Water Conveyance System

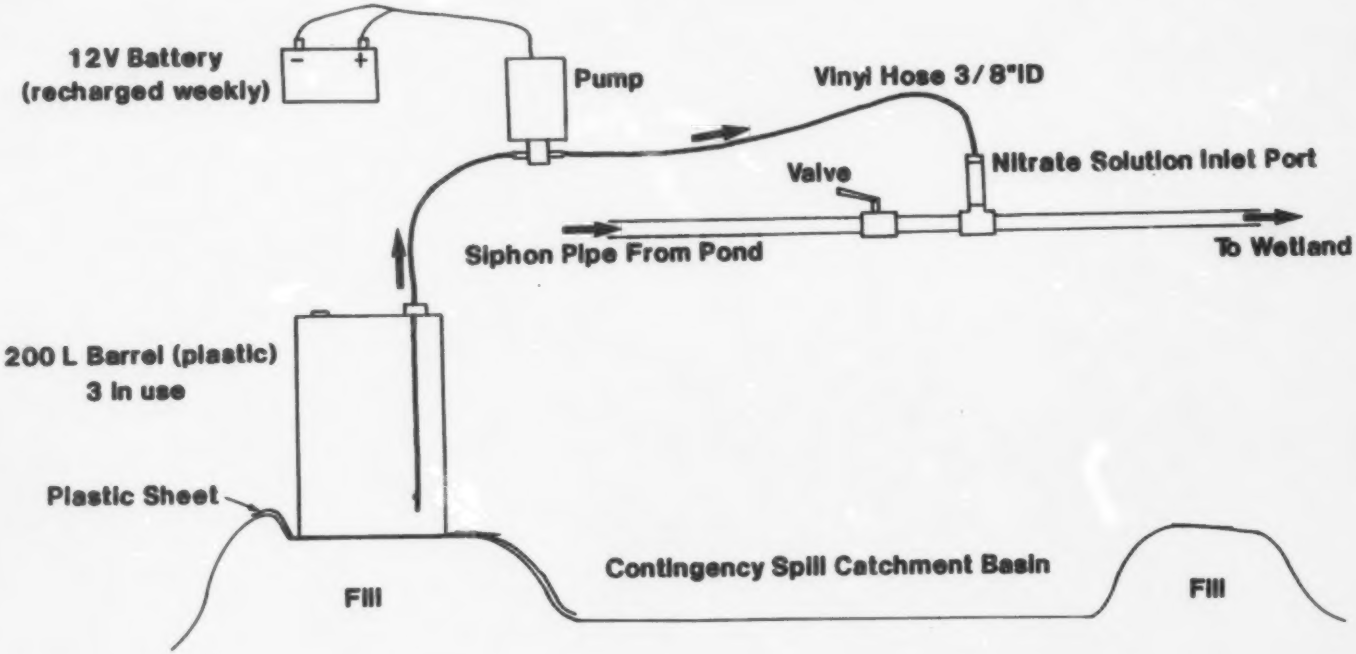
The water supply to the experimental wetland was obtained from the settling pond via a siphon made of 2.5 cm diameter flexible PVC pipe (Figure 3.1-3). The screened siphon intake was fixed at approximately 0.5 m below the water surface by attaching the pipe to a floating log. The siphon pipe was initially placed over the settling pond dam, but was subsequently re-installed on the inside of the settling pond drain pipe to prevent siphon failure due to low water levels in the settling pond in late summer.

Flow to the wetland was controlled by a valve located below the siphon, adjacent to the nitrate dosing station (described below). A length of pipe below the valve conveyed the water to the wetland inlet. The wetland inlet consisted of a manifold to distribute the influent. Outflow from the experimental wetland was via a Parshall flume (Figure 3.1-3). The effluent then flowed through a ditch to a discharge channel from the settling pond and into the natural wetland (Figure 3.1-3).

3.1.5 Nitrate Dosing System

Initial water quality analysis revealed that nitrogen content of Quinsam Coal drainage water was lower than typical coal mine effluent. Nitrate addition to the settling pond effluent was necessary to simulate a level of nitrate enrichment that would require treatment. A dosing system, consisting of nitrate solution reservoirs, a calibrated metering pump, and a battery power supply, was therefore installed (Figure 3.1-5). In April 1989, the entire dosing station was housed in a shed (Plate 4, Appendix C).

Concentrated nitrate stock solution was prepared as needed by dissolving granular potassium nitrate (KNO_3) fertilizer in settling pond effluent stored in 200 L plastic barrels. The nitrate-N content of the stock solution was 5-7 g/L. Several barrels of stock solution were prepared at one time. Each barrel provided stock solution for approximately 7-8 days. A covered catchment basin with a plastic liner was constructed to contain any accidental spill of the stock solution (Figure 3.1-5).


12V Battery
(recharged weekly)
−
+
Pump
Vinyl Hose 3/8"ID
Nitrate Solution Inlet Port
Valve
Siphon Pipe From Pond
To Wetland
200 L Barrel (plastic)
3 in use
Plastic Sheet
Contingency Spill Catchment Basin
Fill
Fill

NOTE: The barrels, pump, battery and basin
are enclosed in a wooden shed.

SCHEMATIC OF POTASSIUM NITRATE DOSING SYSTEM
USED AT THE EXPERIMENTAL WETLAND

Figure no. 3.1−5	QUINSAM WETLAND PROJECT
Date Mar. 1992	Drawn by NORECOL

Delivery of the nitrate stock solution to the influent occured immediately below the flow control valve in the influent delivery pipe (Figure 3.1-5). Complete mixing occurred in the pipe between the dosing station and the wetland inlet manifold (a distance of approximately 30 m) (Figure 3.1-3).

During Years 2 and 3, the dosing pump was calibrated to produce a higher influent NO_3-N concentration (>20 mg/L) than during Year 1 (10 mg/L).

3.2 Operation

3.2.1 Hydrology

Surface flows into and out the wetland were measured weekly. The inflow was measured using a bucket and stop watch. Outflows from each wetland basin were measured with a Parshall flume (1 inch throat width). Exfiltration was estimated from slug tests in the two 0.75 m deep piezometers installed in the wetland (Figure 3.1-3) and from published information.

3.2.2 Water Quality

Triplicate water samples were collected weekly at the wetland inlet, midpoint and outlet. During Year 2, water samples were collected from March 15, 1989 to February 12, 1990; sampling was suspended for approximately one month due to freezing conditions, and resumed in mid March, 1990. A single sample was collected weekly from the barrels containing nitrate stock solution. Analytical parameters are listed in Table 3.2-1. Sample filtration and/or acidification with HCl was carried out in the field laboratory, immediately after collection. Samples were iced and shipped to the laboratory in Vancouver within 24 hours of collection.

Organic nitrogen concentrations were estimated by subtracting inorganic nitrogen (ammonia-N, nitrate-N and nitrite-N) from total N. Particulate fractions of nutrients and metals were estimated by subtracting dissolved (filtered samples) from total concentrations (unfiltered samples).

During Year 3, surface water samples were collected from April 3, 1990 to October 22, 1990. Sampling was suspended between November 1990 and January 1991, due to lack of funds, and was resumed on February 4 through March 31, 1991. Groundwater samples were collected in March, May and July 1990, as well as in March 1991.

TABLE 3.2-1

WATER QUALITY PARAMETERS AND SAMPLING FREQUENCY FOR SAMPLES COLLECTED FROM THE EXPERIMENTAL WETLAND

PARAMETERS	SAMPLING FREQUENCY		
	WEEKLY	BI-WEEKLY[a]	MONTHLY
pH	X		
Conductivity	X		
Suspended Solids	X		
ammonia-N	X		
Nitrate-N	X		
Nitrite-N	X		
Total-N	X		
Orthophosphate-P	X	X	
Dissolved-P	X	X	
Total-P	X	X	
Metals (total and dissolved)[b]			X

a Year 1 only
b Al, Fe, Cd, Cu, Pb, Mg, Zn

3.2.3 Soil Composition

Surface soil samples (top 20 cm) were collected from the center of the upper and lower basins of the wetland, using a 5 cm inside diameter plastic corer. The soil cores were packed in sealed plastic bags and shipped to the laboratory on the day of collection. Analytical parameters are listed in Table 3.2-2. Although the fate of heavy metals was beyond the scope of this project, soil metals data were obtained for possible future detailed analysis and interpretation.

Soil samples were collected in May and August 1990 and again in March 1991, from one sample site within each basin and from a control site (Figure 3.1-2) in the adjacent natural wetland. Samples were collected with a metal auger from 0-10 cm, 30-40 cm and 60-70 cm below ground level.

3.2.4 Vegetation

Cattail and sedge plant heights were measured in late July 1989. Sedge root and shoot samples from each wetland basin, and sweetgale shoot samples from the lower basin, were collected in July 1989 for tissue composition analysis. Cattail tissue was not sampled in 1989, pending establishment of the transplanted stand.

Above and below-ground samples of cattail, sedge and sweetgale tissue were collected monthly from April through August 1990, and in March 1991. Samples from the control site (Figure 3.1-2) were also collected. Analytical parameters are listed in Table 3.2-2.

Three 0.25 m^2 (0.5 m by 0.5 m) plots were established in the experimental wetland. All above ground vegetation within each plot was removed on March 14, 1990 and again on February 27, 1991. The dry matter from each plot was used as a basis for estimation of above-ground standing crop (biomass) and productivity.

3.2.5 Nutrient Mass Balance

Mass loading and discharge of nitrogen and phosphorus were estimated from the concentration and flow data for the inlet and outlet, including precipitation. Nutrient removal efficiencies were calculated on a mass basis. The apportionment of nutrient removal among microbial, vegetation, exfiltration and other pathways was carried out to the extent possible (i.e. microbial and below-ground plant biomass components were estimated by subtraction only).

TABLE 3.2-2

CHEMICAL PARAMETERS MEASURED IN VEGETATION AND SOIL SAMPLES COLLECTED FROM THE EXPERIMENTAL WETLAND

VEGETATION (Shoots and Roots)[a]	SOIL
Total-N	Total-N
Total-P	Inorganic-N
Metals[b]	Total-P
	Metals[c]
	pH
	Organic Matter

[a] Analyzed separately.
[b] Al, Cd, Cr, Na, K, Fe, Cu, Pb, Mn, Mg, Si, Zn
[c] Al, Cd, K, Fe, Cu, Pb, Mg, Zn

RESULTS AND DISCUSSION

This chapter details the results obtained during Year 3 and provides a comparison with Years 1 and 2. The reader is referred to the annual reports for a detailed description of the Year 1 and 2 results (Norecol 1989, 1990). It should be noted that statistical analyses were carried out only for nitrogen water quality data.

4.1 Hydrology

4.1.1 Surface Inflows and Outflows

Measurement of flow into and out of the experimental wetland during the final five months of Year 2 and during Year 3 are shown in Table 4.1.1-1. Flow data for the midpoint were first obtained in June 1990 after the Parshall flume was installed. As during previous years, inflows tended to decrease over time from the initial level (set at) 20 m^3/d in March 1990 to a minimum of 10 m^3/d in mid summer, due primarily to build-up of a biofilm on the inside of the supply hose. The biofilm was periodically removed by threading through the hose a bottle brush attached to a long cable. A secondary cause of inflow reduction was the seasonal drop in the mine settling pond water level, which diminished the hydraulic head driving the gravity feed siphon from the pond to the experimental wetland.

Outflows were usually less than inflows, ranging between 8 to 13 m^3/d in the upper basin and 4 to 20 m^3/d in the lower basin. The greatest difference between inflows and outflows occurred during rainless periods in spring and summer, and was probably due to evapotranspiration and exfiltration (Figure 4.1.1-1).

4.1.2 Precipitation

The precipitation record for the minesite is shown in Figure 4.1.2-1. Periods of higher rainfall occurred between April and June 1990, and especially during repeated storms between late September 1990 and February 1991. Throughout most of the Year 3 growing season, precipitation represented less than 10 percent of the piped inflow. However, during the fall and winter storms, rainfall added a further 28 to 78 percent above the piped water supply. The precipitation fraction of outflows accounted for 5% during the summer and ranged from 38 to 130% during the fall and winter.

The outflow from the upper and lower basins (Basins 1 and 2, respectively) during Year 3 averaged 68 and 74 percent of the initial inflow (Table 4.1.1-1). However, the outflows exceeded or equalled the inflows during periods of elevated precipitation in June 1990, and during the spring freshet in March 1991 (Figure 4.1.1-1). During the

TABLE 4.1.1-1

SUMMARY OF MONTHLY INFLOW AND OUTFLOW VOLUMES FOR THE EXPERIMENTAL WETLAND FOR NOVEMBER 1989 TO MARCH 1991

MONTH (a)	INFLOW m3/d	PRECIP mm	PRECIP % INFLOW	ET mm	ET % INFLOW	LEAKAGE m3/d	LEAKAGE %T.INFLOW	OUTFLOW m3/d	OUTFLOW % INFLOW	HRT Days
JANUARY	9.1	114	32.43%	6.141	1.75%	2.2	23.9%	7.0	76.9%	8.8
FEBRUARY	15.9	172	30.98%	24.206	4.36%	11.7	73.7%	3.8	23.9% b	5.0
MARCH	17.6	41	6.02%	30.574	0.45%	-20.1	-114.5%	37.3	212.0% c	4.5
APRIL	18.0	51	7.57%	46.639	0.69%	6.7	37.4%	10.4	57.6%	4.5
MAY	16.4	67	10.52%	63.091	9.91%	7.0	42.4%	8.1	49.4%	4.9
JUNE	15.3	86	14.99%	75.263	1.31%	-4.7	-30.6%	18.1	118.6%	5.2
JULY	13.0	11	2.19%	84.864	16.90%	5.2	40.0%	5.7	43.7% d	6.2
AUGUST	15.1	10	1.71%	83.781	14.29%	8.0	52.6%	5.0	33.3%	5.3
SEPTEMBER	15.2	23	4.03%	71.045	1.24%	4.3	28.0%	9.1	59.5%	5.3
OCTOBER	18.5	201	27.98%	51.178	7.12%	5.8	31.3%	11.4	61.6%	4.3
NOVEMBER	11.5	335	77.55%	31.124	7.20%	-	0.0%	-	- e	6.9
DECEMBER	9.7	103	27.35%	17.729	4.71%	2.2	22.7%	7.1	72.6%	8.2
YEAR	14.6	101.2	20.28%	48.8	5.83%	2.6	17.2%	11.2	73.5%	5.8

a	values for 1989,1990 and 1991 have been averaged where applicable
b	freezing conditions; inflow froze in wetland
c	spring freshet: melt-down of accumulated ice and snow
d	flooded outlet weir; measurement difficulties
e	not measured in 1990; project shut down
ET	Evapotranspiration
HRT	Hydraulic retention time

FLOW MEASUREMENTS INTO AND OUT OF THE EXPERIMENTAL WETLAND FOR NOVEMBER 1989 TO MARCH 1991

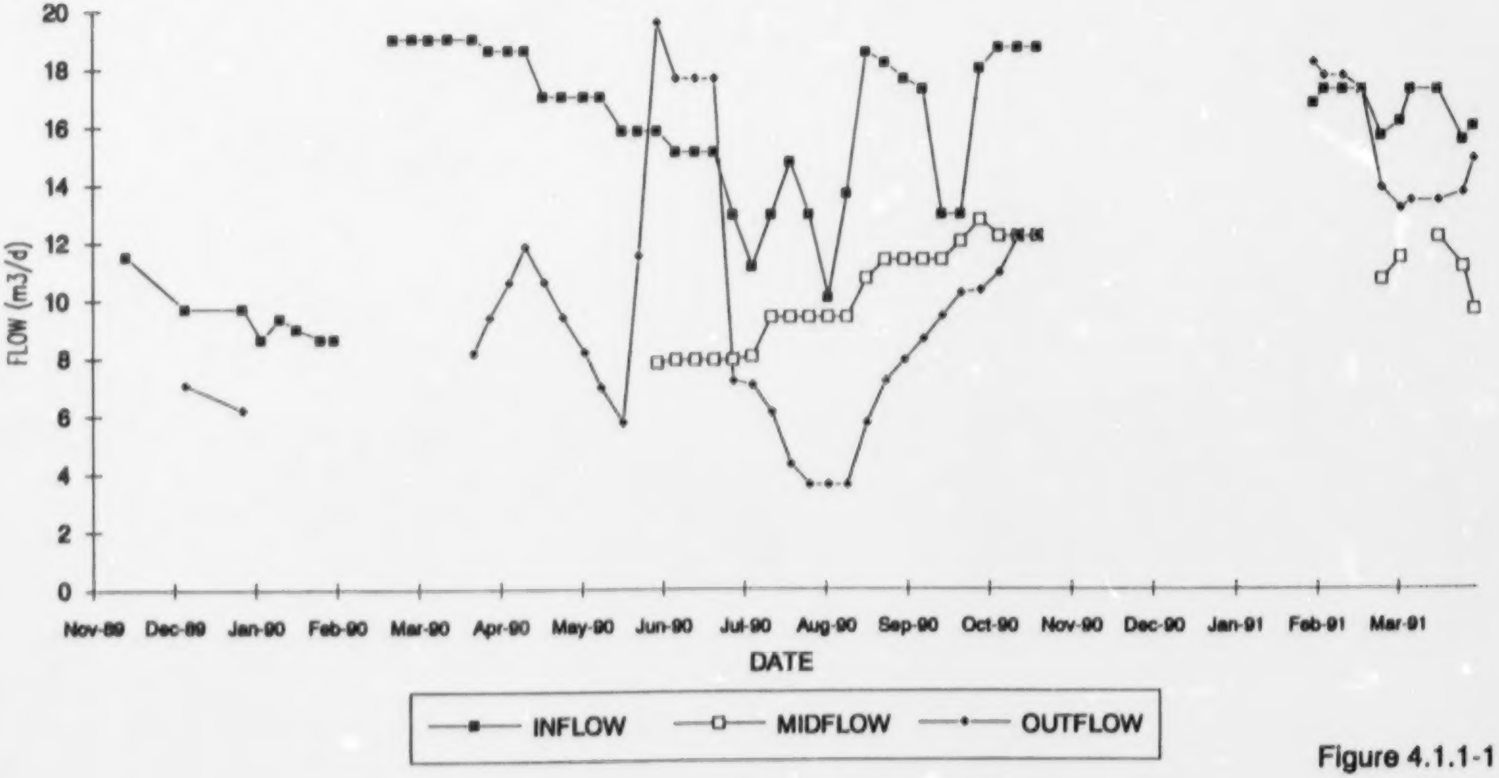


Figure 4.1.1-1

PRECIPITATION RECORD FOR THE QUINSAM MINESITE FOR NOVEMBER 1989 TO MARCH 1991

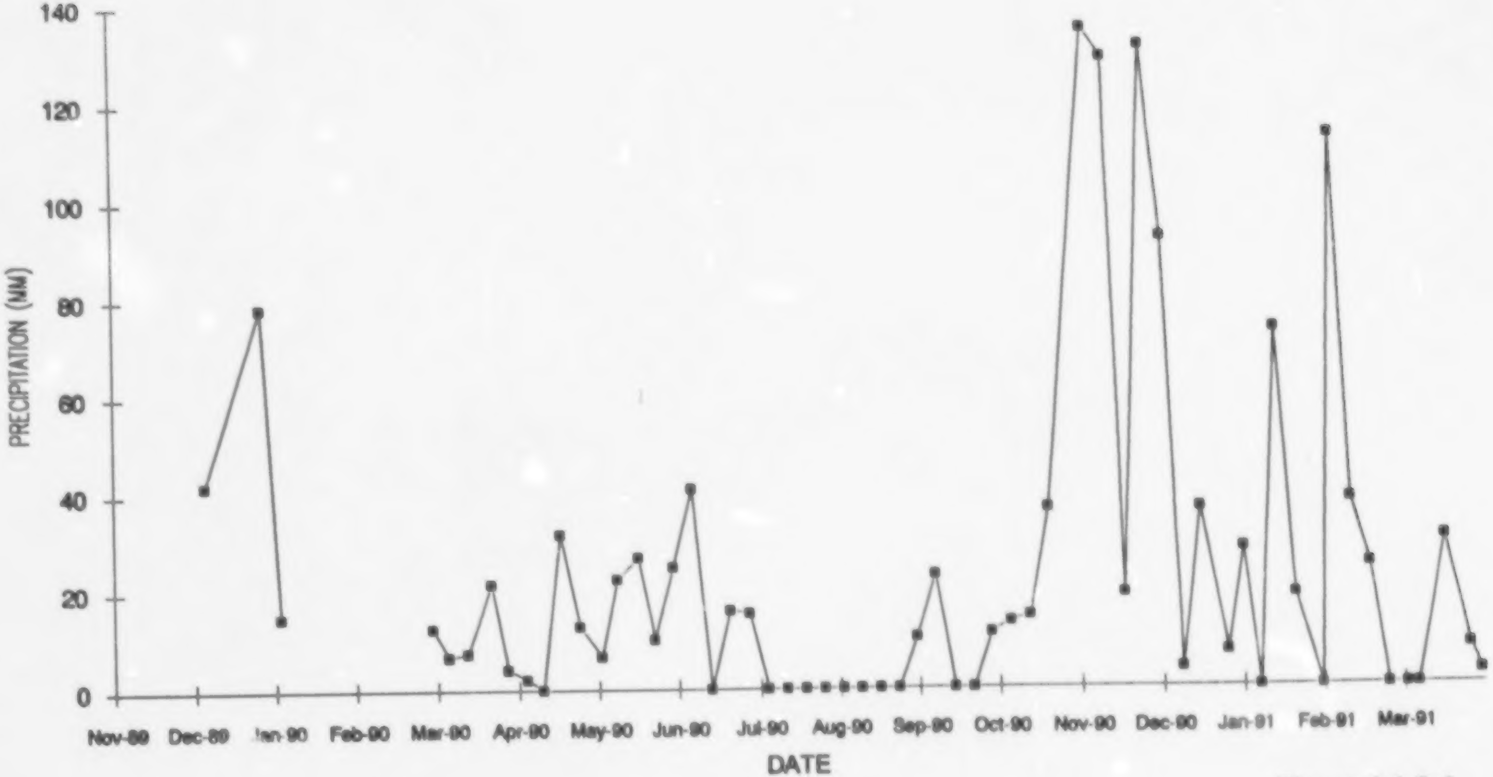


Figure 4.1.2-1

summer drought period, the discharge from the upper basin was 49.4 percent of the inflow, whereas in the lower basin, the discharge was 53.6 percent of its inflow.

4.1.3 Evapotranspiration

Evapotranspiration (ET) was estimated using the Thornthwaite method (Chow 1964, in Mitsch and Gosselink 1986) which is based largely on mean monthly ambient temperature. ET estimates are shown in Table 4.1.1-1. On an annual basis, the average water loss via ET was 5.8% of the piped inflows. Maximum levels of ET took place in July and August (14 to 17% of inflow) and the lowest occurred in January (1.8% of inflow). In August 1990, the final discharge was approximately 74% lower than the inflow, due largely to ET water loss in the two wetland basins.

4.1.4 Exfiltration and Leakage

Leakage and exfiltration were estimated by subtraction, based on the following formula:

$$\text{Exfiltration} + \text{Leakage} = \text{Inflow} + \text{Precipitation} - \text{Outflow} - \text{ET}$$

Outflow from Basin 2 averaged 115 percent of the measured inflow to this basin, possibly reflecting subsurface leakage from the upper to the lower basin.

4.1.5 Hydraulic Retention Time

The theoretical hydraulic retention time (HRT) in the experimental wetland, based on piped inflows only, ranged between 4.3 days in October and 8.8 days in January. During rainy periods, however, an additional 8 m^3/d was added for every 10 mm/d of precipitation. Retention times in each of the two basins including rainfall were therefore between 1.7 and 3.4 days. During peak rainfall events, the HRT would have been further reduced temporarily, increasing the flushing rate (and possible suspension of particulates) and diluting the concentrations of dissolved substances.

4.2 Soils

4.2.1 Soil Organic Matter

Comparison Between Sites and Depths

Organic matter content (approximated as volatile solids (VS) or loss on ignition) averaged 50.5% (dry matter basis) in Basin 1, 62.5% in Basin 2, and 59.3% in the Control (Table 4.2.1-1). The high organic matter content reflects the peaty nature of the soils at the experimental site. Nutrient reserves in such soils are known to be high though generally unavailable until the material is mineralized through decomposition (Mitsch and Gosselink 1986). Decomposition rate of wetland vegetation litter by micro-organisms is known to increase with an increase in the availability of nitrogen (Hopkinson et al. 1978). The differences between sites probably reflect natural variability. The lower surface VS content in Basin 1 than Basin 2 may, however, reflects the higher mineralization rate in the presence of higher nitrogen inputs via the dosed influent.

Lowest VS content consistently occurred in the older, more mineralized soils at 60 to 70 cm, whereas the highest VS content occurred in the 30 to 40 cm samples. The difference between the 0 to 10 cm and 30 to 40 cm samples, although small and not discernible from natural variability (Figure 4.2.1-1), may also reflect the higher rate of mineralization at surface due to greater availability of nitrogen and oxygen for aerobic and facultative micro-organisms.

Comparison Between Years

Soil VS content in Year 3 (range 27.9 to 71.3%) was lower than values measured in Year 2 (range 69.2 to 78.7%; Norecol 1990) and at the beginning of Year 1 (range 72.9 to 74.6%; Norecol 1989). This reduction may be attributed to natural variability and, possibly, to the increased rate of mineralization resulting from the additional nitrogen inputs.

4.2.2 Soil Nitrogen

Comparison Between Sites

Soil N content in Basin 1 and 2, and at the control site is shown in Figure 4.2.2-1. Average N content was lowest in Basin 1, and was similar in Basin 2 and the Control site. Within the experimental wetland, soil N was higher in the upper two strata, and consistently lowest in the 60 to 70 cm stratum. In Basin 1, nitrogen decreased with depth, whereas in Basin 2, N increased slightly between surface and 40 cm, thereafter decreasing with depth. At the Control site, soil N was lowest at the surface and similar at the two lower strata.

TABLE 4.2.1-1

AVERAGE SOIL ORGANIC MATTER CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE

	BASIN 1			BASIN 2			CONTROL		
DATE	S1-1	S1-2	S1-3	S2-1	S2-2	S2-3	C-1	C-2	C-3
	0-10 cm	30-40 cm	60-70 cm	0-10 cm	30-40 cm	60-70 cm	0-10 cm	30-40 cm	60-70 cm
02/06/90	73.4%			71.3%					
05/15/90							65.4%	62.0%	46.4%
08/21/90	55.5%	60.9%	35.9%	64.3%	71.3%	27.9%	53.6%		55.4%
03/27/91	44.9%	69.1%	36.1%	68.1%	69.7%	65.0%	62.0%	63.8%	65.8%

Note: Soil organic matter content equivalent to loss on ignition or volatile solids.

COMPARISON OF SOIL ORGANIC MATTER CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL
SITE 1990-1991

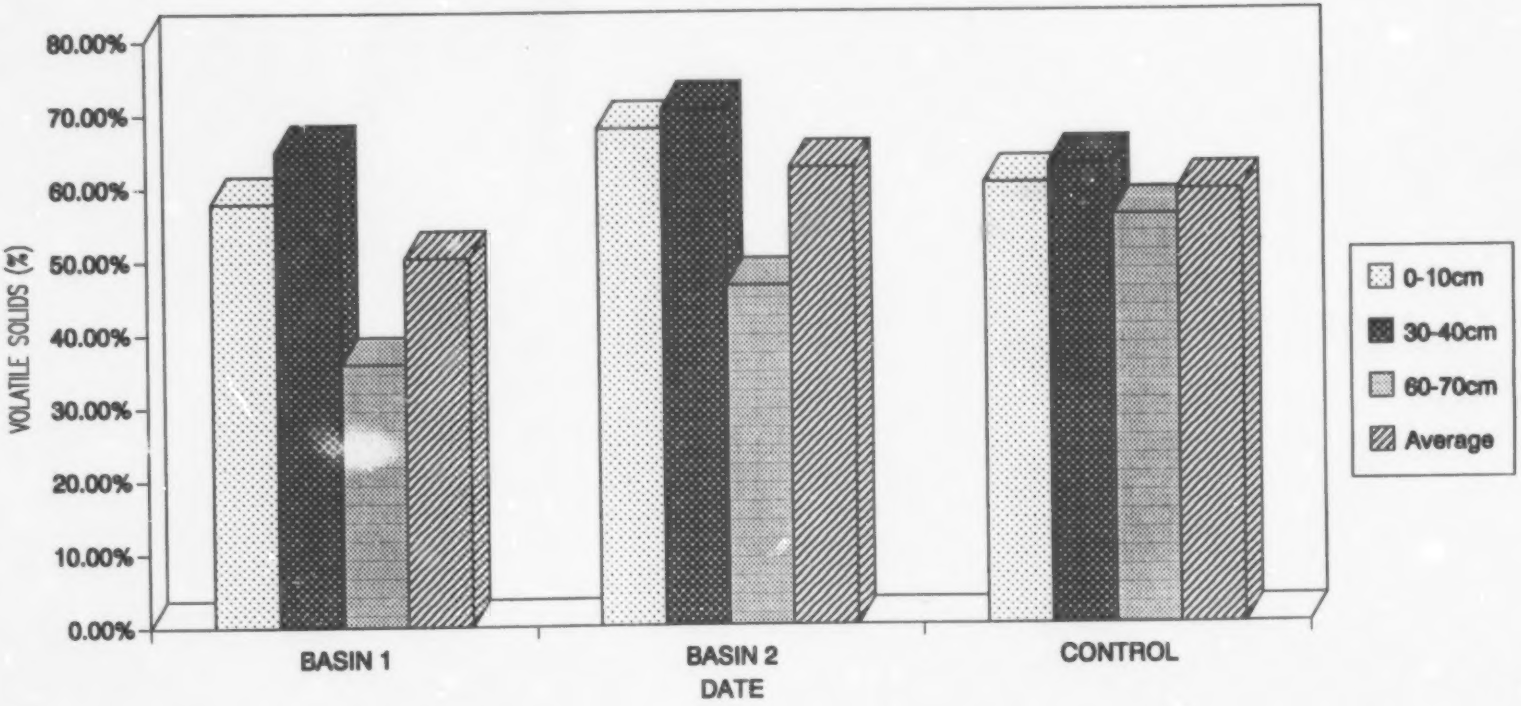


Figure 4.2.1-1

COMPARISON OF SOIL NITROGEN CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

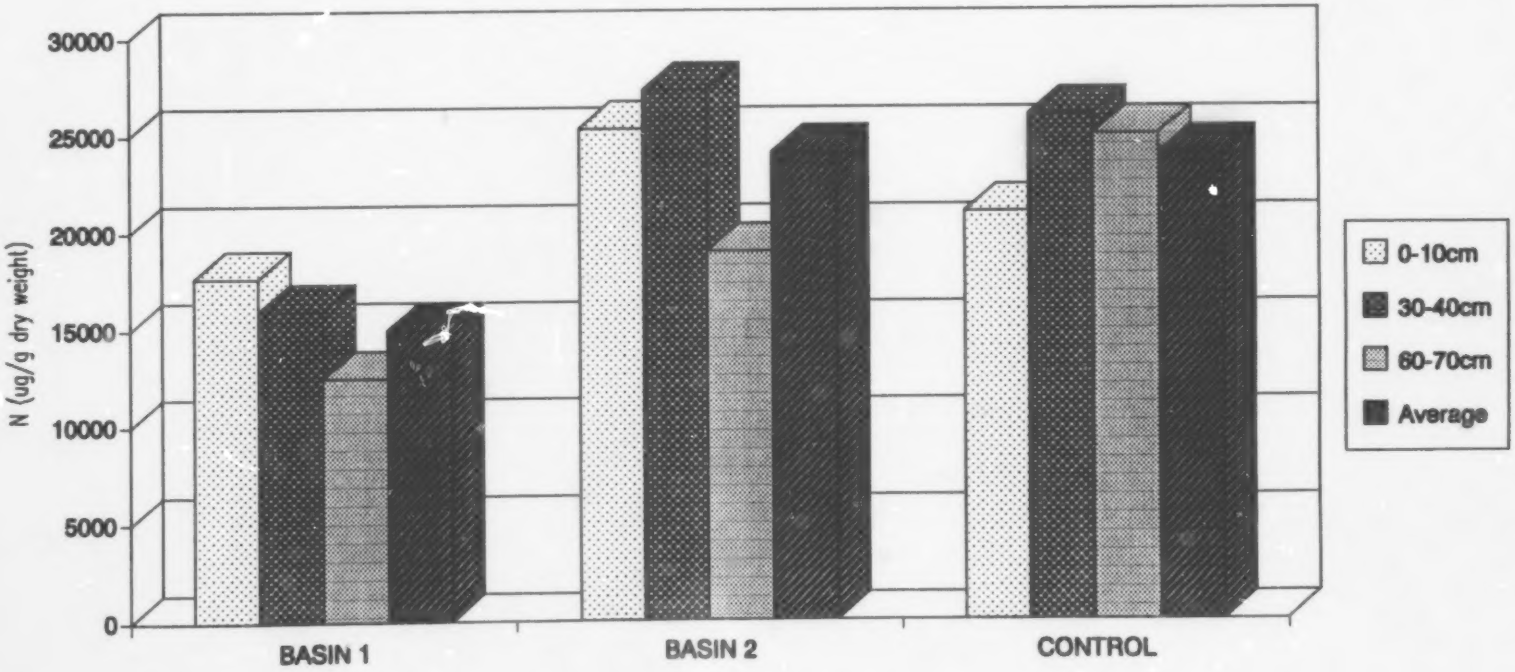


Figure 4.2.2-1

The differences in soil N content with depth within the experimental wetland can probably be attributed to the nitrate dosing. The higher overall N levels in Basin 2 and the Control probably reflect a greater similarity in soil composition and overlying vegetation at these two locations as compared to Basin 1. Soils in Basin 2 and the Control site are deeper than in Basin 1 and the pre-disturbance vegetation cover was dominated by sweetgale, as opposed to sedge in Basin 1.

Further sampling would be required to ascertain whether the higher N content at depth in the Control site compared to the experimental sites is a consistent trend or merely an artifact of the limited data set.

Seasonal Changes

Figure 4.2.2-2 summarizes limited data obtained on seasonal changes in soil N at the different sites. Surface, N in Basin 1 decreased substantially between late winter (February) 1990 and summer (August), and subsequently, by late winter (March) 1991, increased to a comparable level to that in winter 1990. In Basin 2, N increased slightly between late winter and summer 1990, and decreased subsequently by winter 1991 to a slightly lower level than in winter 1990. In the control, data are available for summer 1990 and late winter 1991 only; during this period, surface soil N decreased slightly, although levels were within the range of Basins 1 and 2.

At 30 to 40 cm, data are available only for summer 1990 and late winter 1991. Basins 1 and 2 both showed an increasing trend over time, although soil N levels in Basin 2 were substantially higher than in Basin 1. In the control, soil N at this depth remained constant between summer and late winter.

At 60 to 70 cm, data are also only available for summer 1990 and late winter 1991. Initial soil N content in both basins was similar. An increasing trend in soil N was measured in both experimental basins, although the increase in Basin 1 was slight compared to the marked increase in Basin 2. The trend in the control was similar to that in Basin 2.

The decrease in surface N in Basin 1 between winter and summer 1990 appears to reflect the removal of soil N by biological uptake during the growing season (Mitsch and Gosselink 1986) despite the addition of nitrate-enriched surface water. Similarly, the subsequent increase in N at all depths in Basins 1 and 2 by the end of the following winter probably reflects the absence of N uptake by plants. Increases in soil N at mid and deeper strata in Basins 1 and 2 may reflect inputs of N from the surface strata and overlying nitrate-enriched water.

SEASONAL CHANGES IN SOIL NITROGEN CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

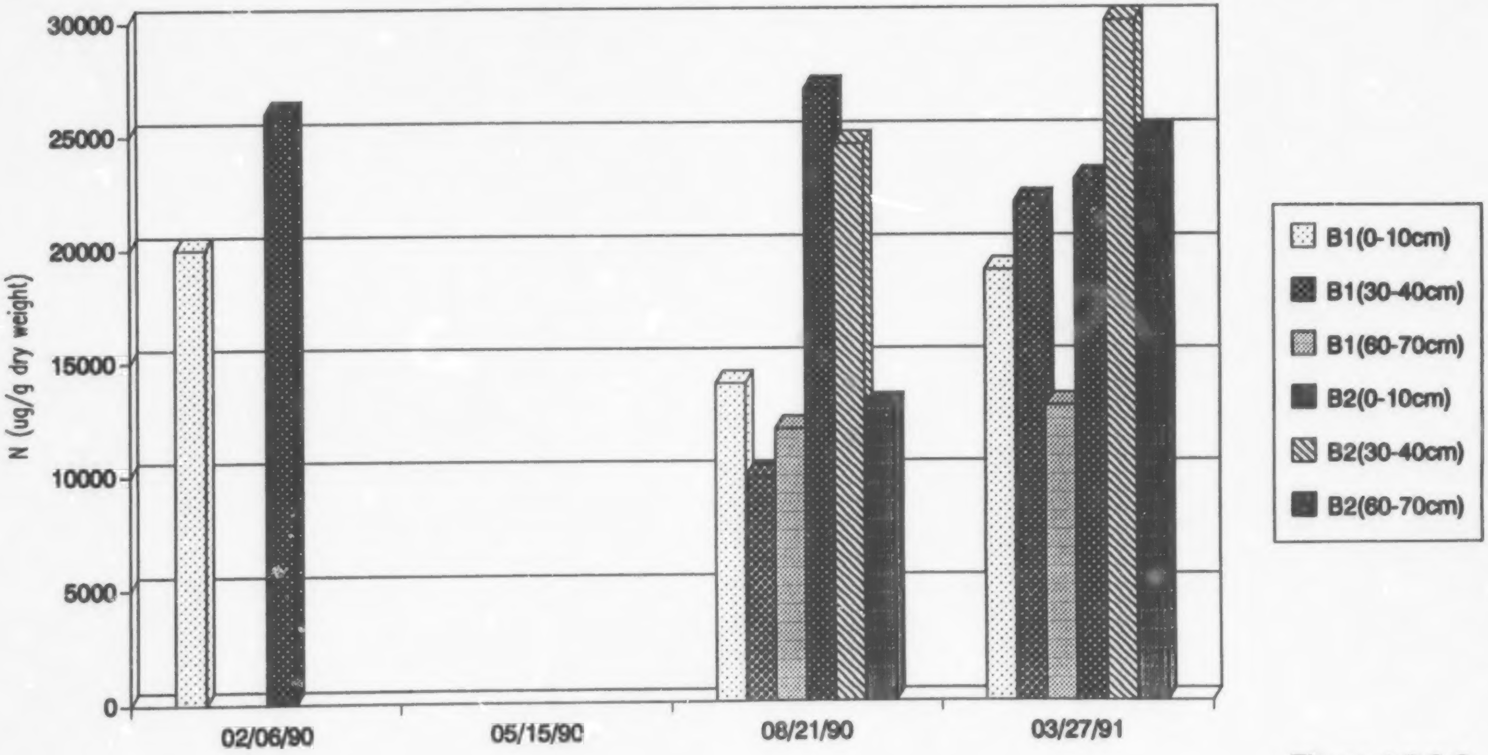


Figure 4.2.2-2

Comparison Between Years

Surface soil N content within the experimental wetland during Year 3 averaged 23,000 ug/g. This value was slightly higher than, although still comparable to, the average value of 21,300 ug/g measured during Year 2 (Norecol 1990). These values are an order of magnitude higher than the surface average of 1,900 ug/g measured at the beginning of Year 1 (Norecol 1989). The increase reflects the effect of nitrate dosing. The high N values measured at the control site in Year 3 suggest that this site may have been influenced by the experimental system.

4.2.3 Soil Phosphorus

Comparison Between Sites

Soil P content within the experimental wetland and at the control site is shown in Figure 4.2.3-1. Average P content was highest in Basin 2 at 1500 ug/g, followed by the Control at 1300 ug/g and Basin 1 at 1100 ug/g. Within the experimental wetland, there was a consistent decrease in soil P content with depth, whereas in the Control, soil P was highest in the 30 to 40 cm stratum and values at the surface and 60 to 70 cm were similar. There was no difference in P content at depth between Basin 2 and the Control site, reflecting the soil depth and vegetation similarities between these two sites (see Section 4.2.2).

Presumably, the high soil P at surface in the experimental wetland reflects the P content in the living (and fertilized) root mass and in the plant litter layer (the lower portion of which was collected during sampling). At the Control site, the higher P content at 30 to 40 cm may reflect a deeper root biomass than occurs in the experimental system, or it may reflect other factors. In this regard, it is interesting to note that soil P at 60 to 70 cm is similar in Basin 2 and the Control.

Seasonal Changes

Seasonal changes in soil P between sites were compared between February 1990 and March 1991 (Figure 4.2.3-2). At surface, values in Basins 1 and 2 increased from February to May, then decreased. In February 1990 and March 1991 (i.e. late winter), surface P values in Basin 1 were similar, whereas values in Basin 2 showed a net decrease between winter 1990 and 1991. (February 1990 data for the control site were not obtained.)

At 30 to 40 cm, P content within both experimental basins increased between May and August and, by March 1991, decreased in Basin 1 and continued to increase in Basin 2. At the control site, P content decreased throughout the same period.

COMPARISON OF SOIL PHOSPHORUS CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL
SITE 1990 - 1991

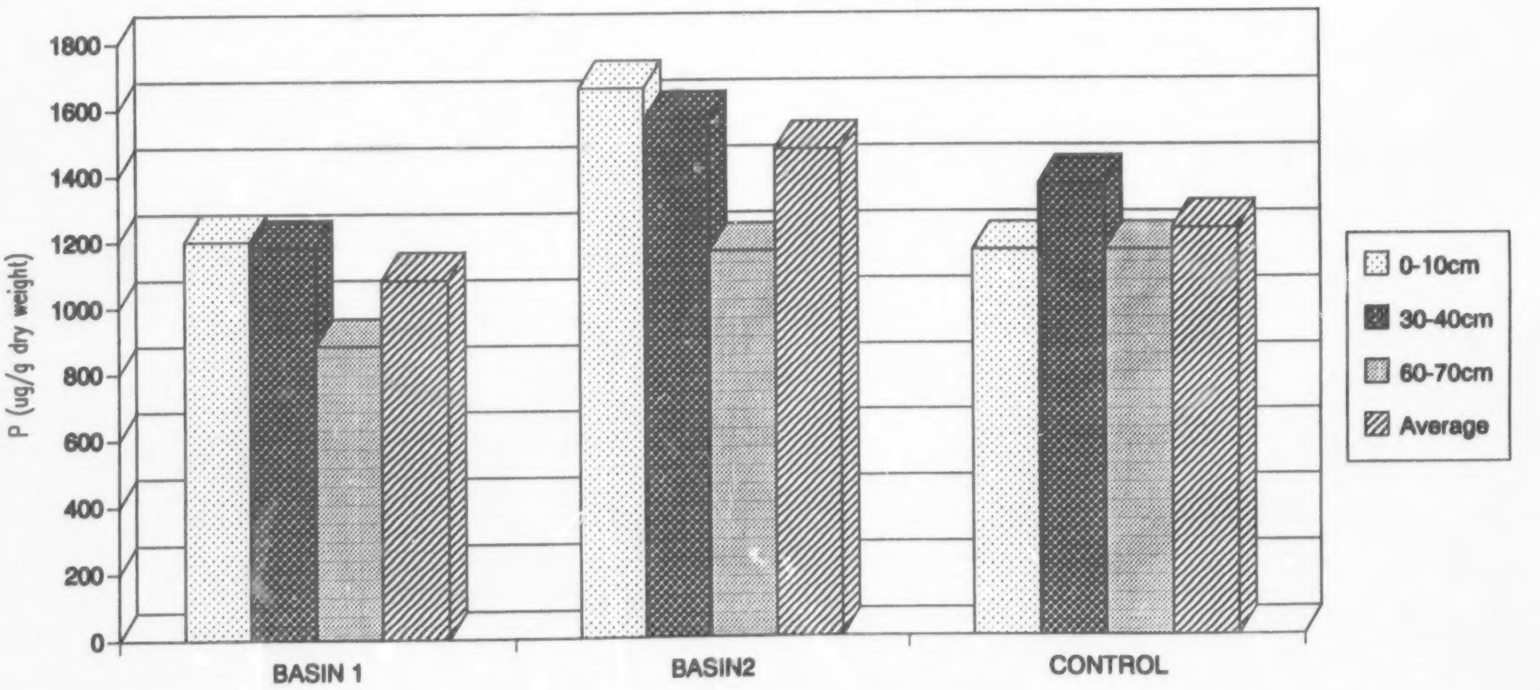


Figure 4.2.3-1

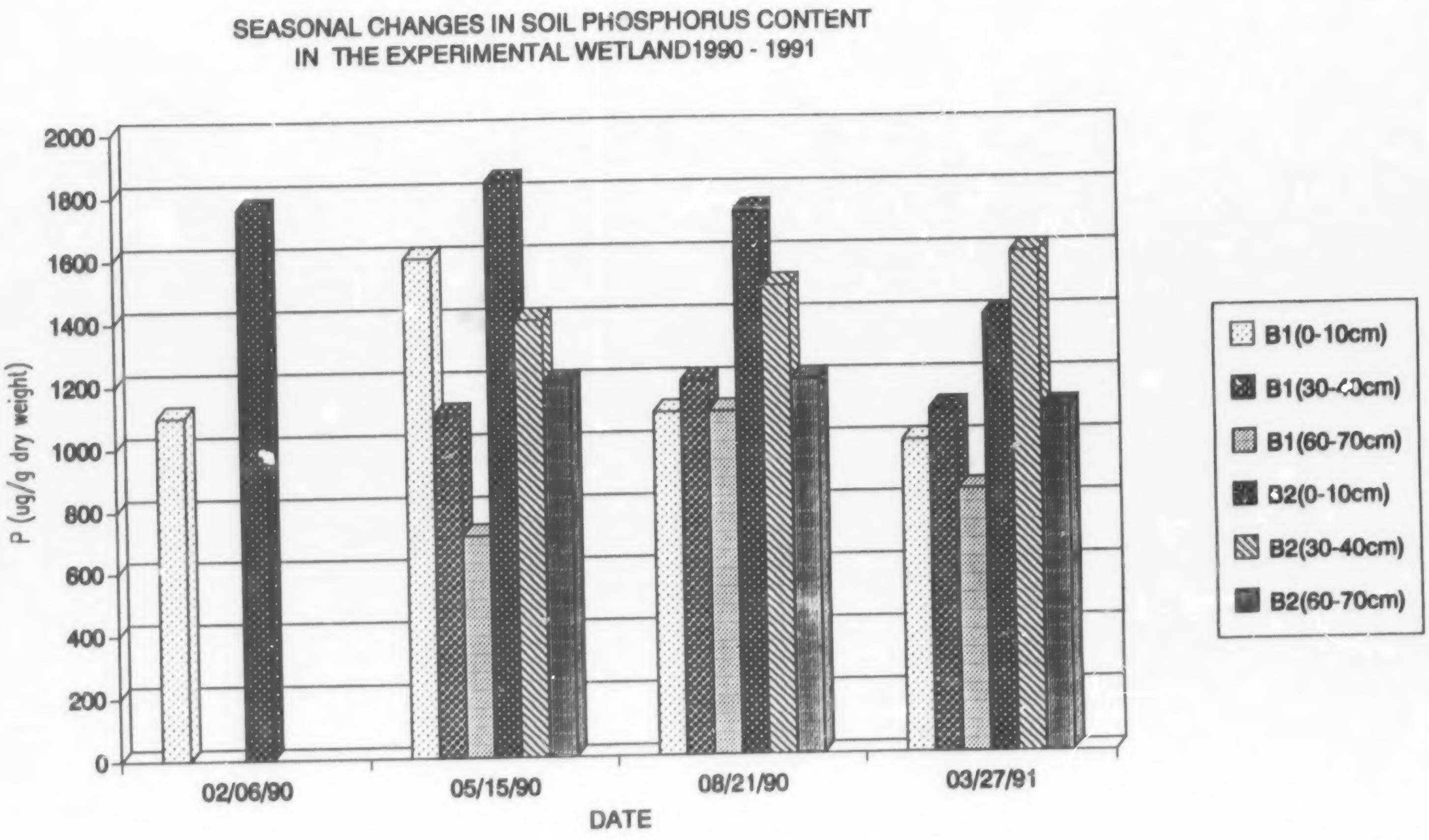

SEASONAL CHANGES IN SOIL PHOSPHORUS CONTENT
IN THE EXPERIMENTAL WETLAND1990 - 1991
P (ug/g dry weight)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
02/06/90
05/15/90
08/21/90
03/27/91
DATE
B1(0-10cm)
B1(30-40cm)
B1(60-70cm)
B2(0-10cm)
B2(30-40cm)
B2(60-70cm)

Figure 4.2.3-2

At 60 to 70 cm, P content in Basin 1 peaked in August and decreased again by March 1991, whereas in Basin 2, P remained constant between May and August, and decreased slightly thereafter. At the control site, P content at this depth followed a similar pattern to Basin 1.

Comparison Between Years

Surface soil P content in the experimental wetland during Year 3 averaged approximately 1400 ug/g. This value is slightly higher than the 1031 ug/g reported for Year 2 (Norecol 1990). Soil P levels measured during Years 2 and 3 are an order of magnitude higher than the average level of 147 ug/g measured at the beginning of Year 1 (Norecol 1989). The increase likely reflects the accumulation of settled particulate matter imported with the influent and of the greater amount of organic matter produced since fertilization was begun. As with soil N, the high P levels measured at the control site during Year 3 compared to the pre-disturbance condition at the beginning of Year 1 suggest that the control site may have been affected by the experimental system.

4.2.4 Soil Metals Content

Soil metals content data were obtained from samples collected in Basins 1 and 2 and in a control site. The control was located in the natural wetland approximately 50 m from the southwest corner of Basin 2 (Figure 3.1-2). As indicated in Section 3.2.3, detailed analysis of the metals results was beyond the scope of this study. Future statistical interpretation of the data will be necessary to ascertain whether any of the differences in metals content observed within and between sites over time can be attributed to causes other than natural variability. A provisional discussion of the soil metal results, without statistical analysis, is provided in Appendix B-3.

4.3 Groundwater

Groundwater quality data were obtained during Year 3 only, at approximately 0.7 m below ground level at one site within each of the two experimental wetland basins. The available data represent four seasonal conditions: late winter/early spring 1990, mid spring 1990, summer 1990, and late winter/early spring 1991. Data analysis included (the major parameters of) pH, conductivity, suspended solids, total organic carbon (TOC) and nitrogen and phosphorus species. Metals have not been addressed, although laboratory data are available (Appendix B-2).

4.3.1 Groundwater pH

Average groundwater pH was 5.8 in Basin 1 and 6.0 in Basin 2 (Table 4.3.1-1) and the pH level in Basin 1 was consistently lower than in Basin 2 (Figure 4.3.1-1). Seasonally, pH tended to decrease from an average of 6.1 in late winter 1990 to 5.8 in spring, and to rise by summer 1990 to 6.0. By late winter 1991, the average groundwater pH had descended to 5.9.

The slightly acidic groundwaters are considered normal for a fen type wetland with organic soil (peat) (Mitsch and Gosselink 1986).

4.3.2 Groundwater Conductivity

Average groundwater conductivity was 274 umhos/cm in Basin 1 and 186 umhos/cm in Basin 2 (Table 4.3.2-1). The conductivity in Basin 2 was usually lower than in Basin 1, except in late winter 1991 (Figure 4.3.2-1). Seasonally, conductivity in Basin 1 tended to increase slightly during the growing season, possibly reflecting the combined effects of addition of solutes due to higher mineralization rate of organic matter during the warm season and increased water loss through evapotranspiration. The seasonal trend in Basin 2 was similar to Basin 1 during the first three sampling dates, but increased above the level in Basin 1 in late winter 1991. This increase may reflect sample contamination (or unknown other causes).

4.3.3 Suspended Solids

Data on suspended solids (SS) are available for spring 1990 only. The average of two replicate samples was 6 mg/L in Basin 1 and 26 mg/L in Basin 2. The higher SS in Basin 2 does not appear to have been due to an increase in dissolved ions, since it is not correlated with conductivity.

4.3.4 Total Organic Carbon

Total organic carbon (TOC) data were obtained in spring and summer 1990 and late winter 1991 (Figure 4.3.4-1). Although the values were within the general range of 19 to 34 mg/L, concentrations were variable between and within basins (Table 4.3.4-1). The least difference between basins occurred in spring, when TOC values were 21.5 mg/L in Basin 1 and 23.5 mg/L in Basin 2. The highest and lowest TOC concentrations were measured during summer, in Basin 2 and Basin 1, respectively. Thus, there appears to be no correlation in groundwater TOC between basins or seasons of year. The results obtained appear to be useful only insofar as they provide a range of TOC values that occurred in groundwater within the experimental system.

TABLE 4.3.1-1

GROUNDWATER pH LEVELS IN BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND 1990 - 1991

BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127	5.90	-	5.90	5.90	1
05/15/90	176	5.65	0.15	5.50	5.80	2
07/10/90	232	6.00	0.00	6.00	6.00	1
03/27/91	492	5.80	0.00	5.80	5.80	1
All samples		5.80	0.17	5.50	6.00	5
C.V.		3%				

BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127	6.30	-	6.30	6.30	1
05/15/90	176	5.85	0.15	5.70	6.00	2
07/10/90	232	6.10	-	6.10	6.10	1
03/27/91	492	5.90	-	5.90	5.90	1
All samples		6.00	0.20	5.70	6.30	5
C.V.		3%				

C.V. = Coeffecient of variation

STD= Standard deviation

GROUNDWATER HYDROGEN ION CONCENTRATIONS IN BASINS 1 AND 2 OF THE EXPERIMENTAL
WETLAND 1990 - 1991

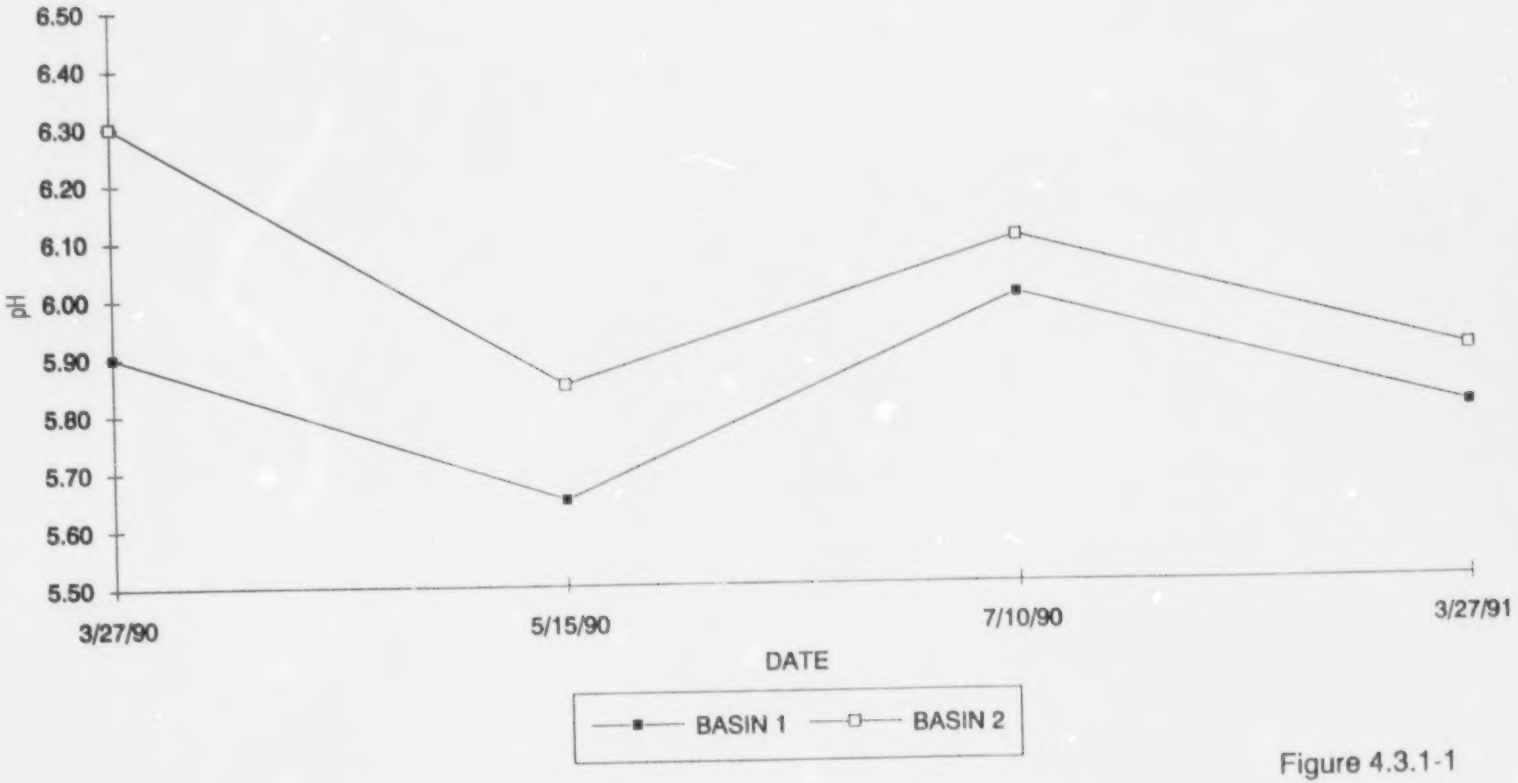


Figure 4.3.1-1

TABLE 4.3.2-1

GROUNDWATER CONDUCTIVITY IN BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND 1990 - 1991

BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127	241	0	241	241	1
05/15/90	176	290	4	286	294	2
07/10/90	232	290	0	290	290	1
03/27/91	492	259	0	259	259	1
All samples		274	21	241	294	5
C.V.		8%				

BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127	136	0	136	136	1
05/15/90	176	158	6	152	164	2
07/10/90	232	167	0	167	167	1
03/27/91	492	309	0	309	309	1
All samples		186	63	136	309	5
C.V.		34%				

C.V. = coefficient of variation

STD = standard deviation

GROUNDWATER SPECIFIC CONDUCTANCE IN BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND
1990-1991

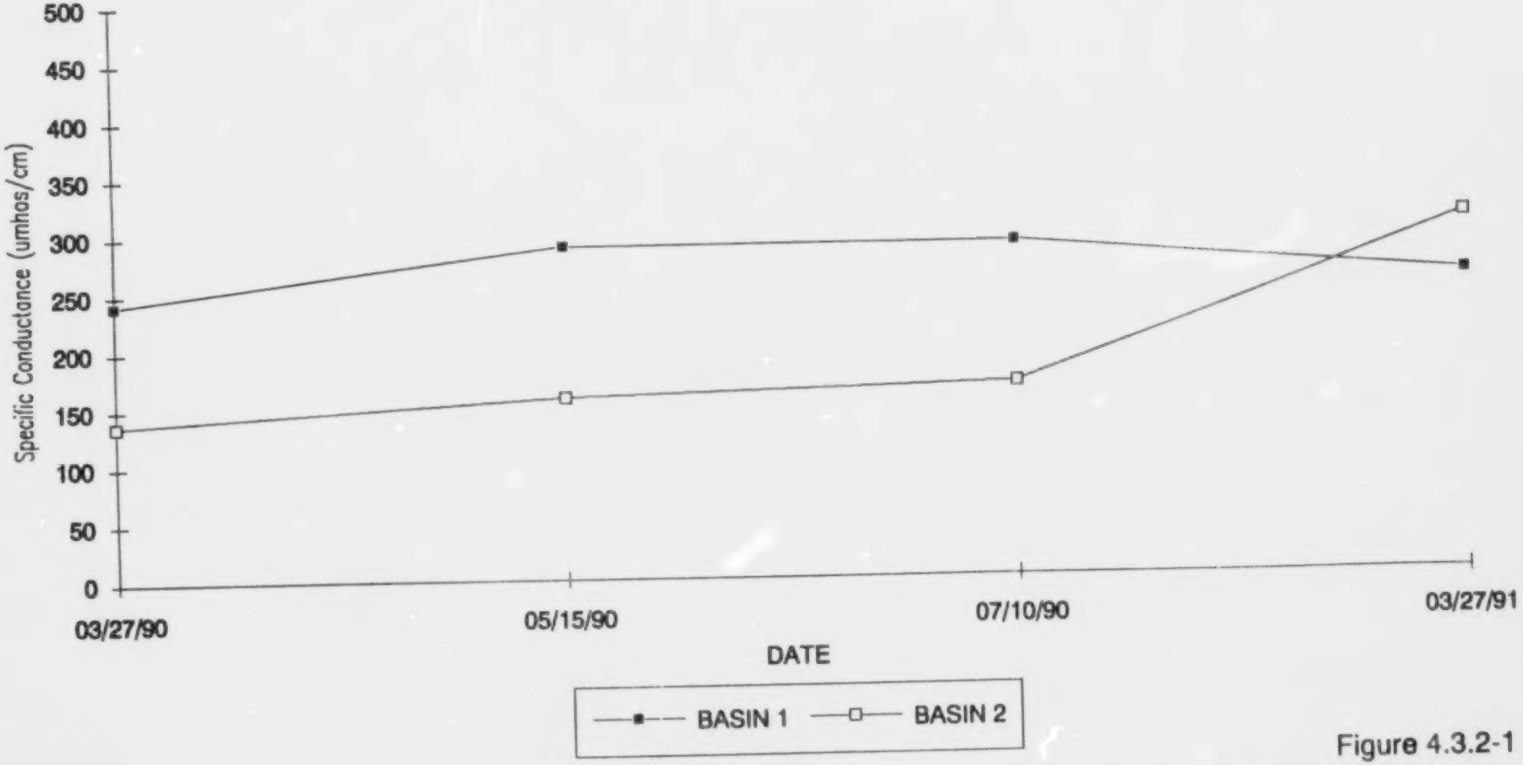


Figure 4.3.2-1

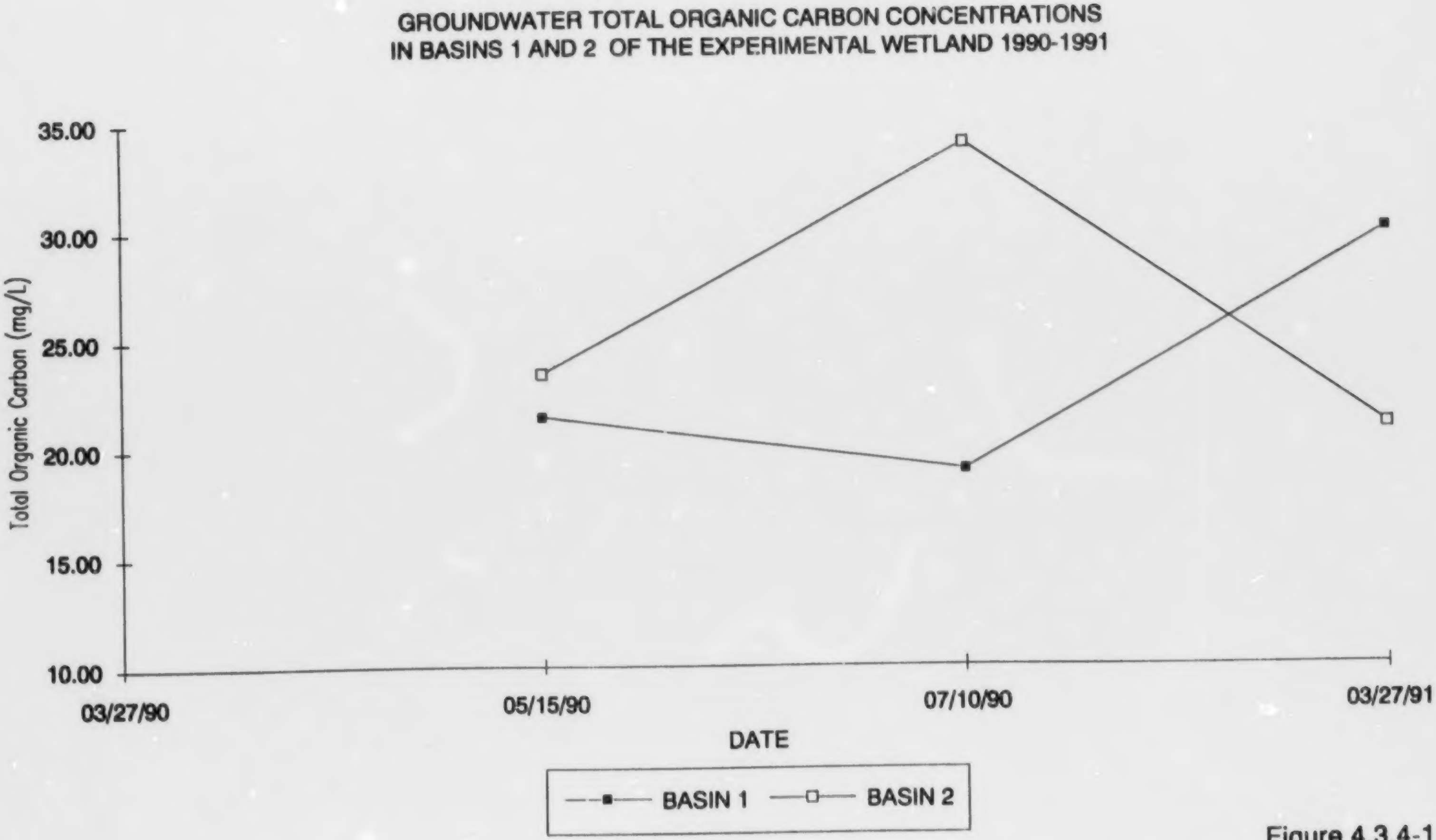

GROUNDWATER TOTAL ORGANIC CARBON CONCENTRATIONS
IN BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND 1990-1991

Figure 4.3.4-1

TABLE 4.3.4-1

GROUNDWATER TOTAL ORGANIC CARBON CONCENTRATIONS IN BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND 1990 - 1991

BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127					
05/15/90	176	21.50	0.50	21.00	22.00	2
07/10/90	232	19.00	0.00	19.00	19.00	1
03/27/91	492	30.00	0.00	30.00	30.00	1
All samples		23.00	4.18	19.00	30.00	4
C.V.		18%				

BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	No.
03/27/90	127					
05/15/90	176	23.50	3.50	20.00	27.00	2
07/10/90	232	34.00	0.00	34.00	34.00	1
03/27/91	492	21.00	0.00	21.00	21.00	1
All samples		25.50	5.59	20.00	34.00	4
C.V.		22%				

C.V. = coefficient of variation

STD = standard deviation

4.3.5 Total Nitrogen

Average concentrations of total nitrogen (TN) in groundwater were 3.8 mg/L in Basin 1 and 4.2 mg/L in Basin 2. The lower TN concentrations in groundwater compared to surface water indicate that the piezometers installation was successful in isolating groundwater from surface water. The groundwater TN data are summarized in Figure 4.3.5-1. Beginning with low TN concentrations in late winter 1990, values increased to a peak in spring 1990, followed by a decrease by summer and a negligible to slight subsequent increase by late winter 1991. The difference in groundwater TN between basins was low during late winter and spring 1990, but increased in summer 1990 and late winter 1991. The high TN concentration in spring may reflect the contribution of N from both the experimental influent and increasing decomposition of organic matter with the onset of warmer temperatures. The decrease by mid summer probably reflects the removal of N from groundwater by microbial and plant uptake.

4.3.6 Nitrate

Average groundwater nitrate concentrations were 0.007 mg/L in Basin 1 and 0.004 mg/L in Basin 2, with an overall range of 0.002 to 0.017 mg/L. The groundwater NO_3 concentrations were considerably lower than in surface waters. The seasonal trends in groundwater nitrate are shown in Figure 4.3.6-1. In late winter 1990, groundwater NO_3 in both basins was at the detection limit of 0.002 mg/L; these low initial concentrations probably reflect the natural background conditions following suspension of nitrate dosing during the winter freeze-up. By spring 1990, concentrations increased, especially in Basin 1, which was receiving the high-nitrate influent. This increase reflects the resumption of nitrate dosing in the experimental influent. In mid summer 1990, groundwater NO_3 had declined to near the detection limits from the levels measured in spring, probably due to the increased rate of nitrate uptake by vegetation and increased denitrification. The highest NO_3 concentrations occurred in late winter 1991. The high values in March 1991 compared March 1990 probably reflect the effect of nitrate dosing to the experimental wetland beginning in February 1991 (which was made possible by the heating system) and the absence of nitrate uptake by the dormant vegetation. The low groundwater NO_3 concentrations in March 1991 do indicate, however, that nitrate removal was occurring in the wetland at this time, probably via dentitrification.

4.3.7 Ammonia

Average groundwater ammonia nitrogen concentrations were higher than in surface water and were similar in both basins (3.06 mg/L in Basin 1 and 3.24 mg/L in Basin 2), with an overall range of 1.69 to 5.12 mg/L. Seasonal trends are shown in Figure 4.3.7-1. Ammonia concentrations were lowest in late winter 1990 and increased markedly by spring, probably reflecting the resumption of microbial decomposition processes (ammonification) with the onset of warmer temperatures

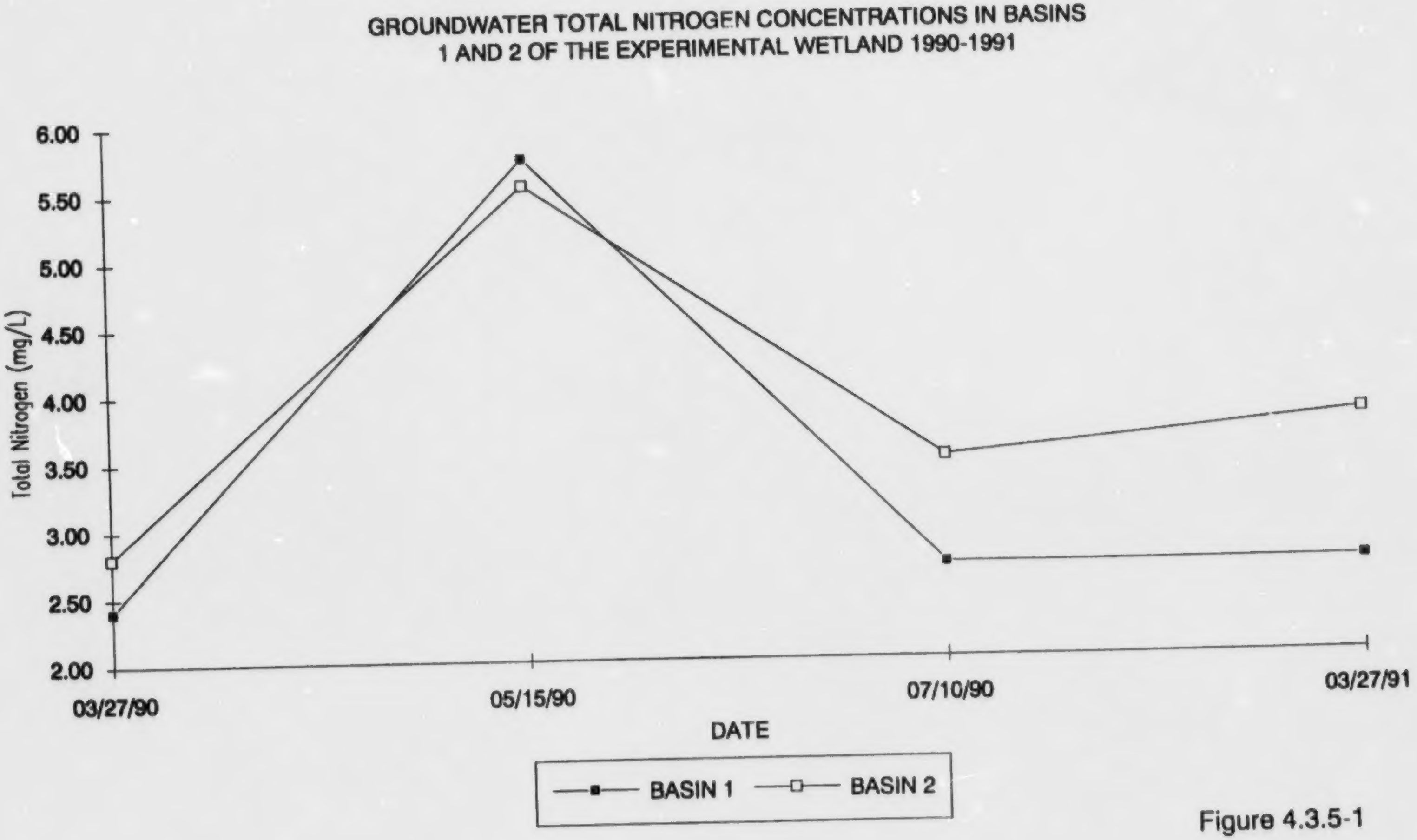

GROUNDWATER TOTAL NITROGEN CONCENTRATIONS IN BASINS
1 AND 2 OF THE EXPERIMENTAL WETLAND 1990-1991

Figure 4.3.5-1

GROUNDWATER NITRATE-N CONCENTRATIONS IN BASINS 1 AND 2
OF THE EXPERIMENTAL WETLAND 1990-1991

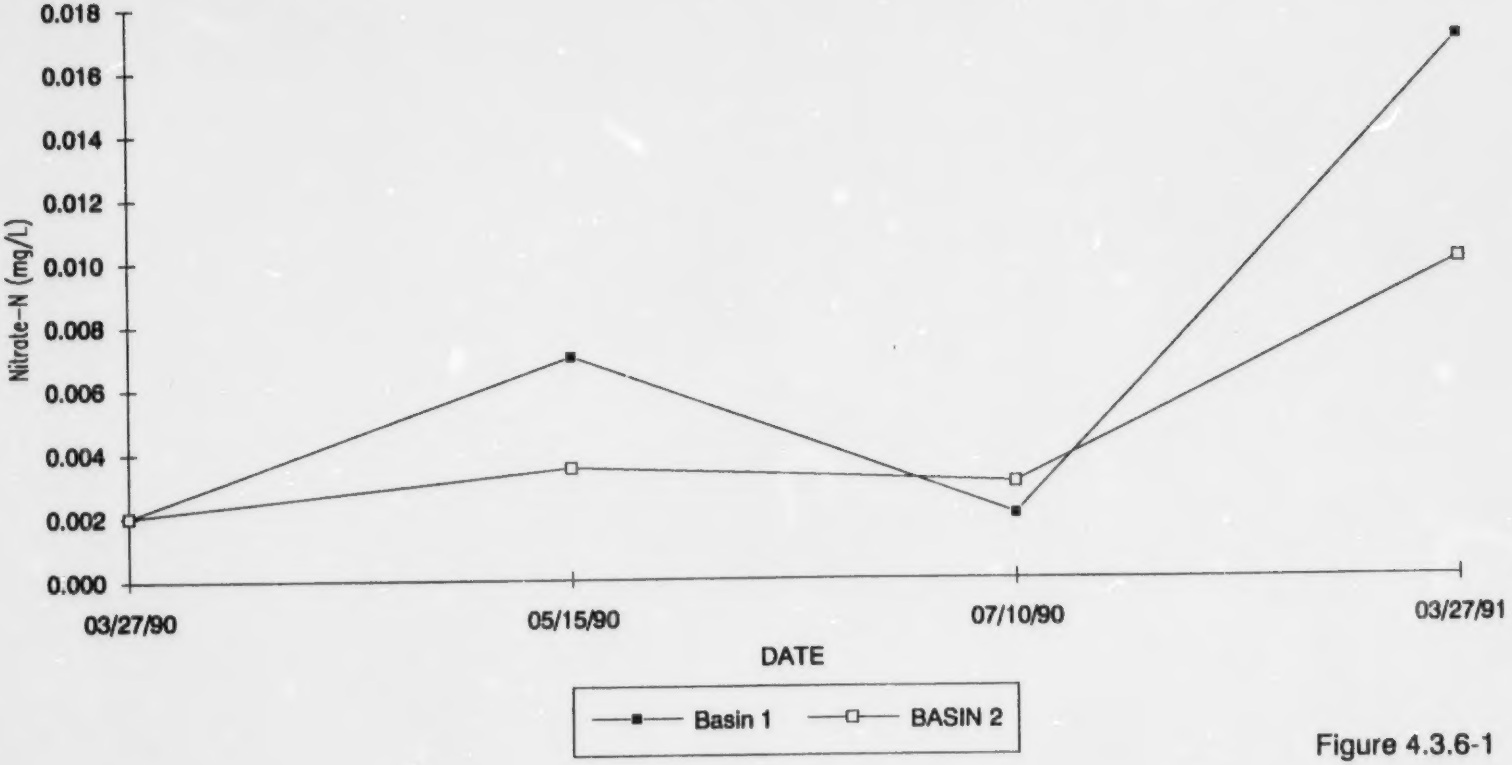
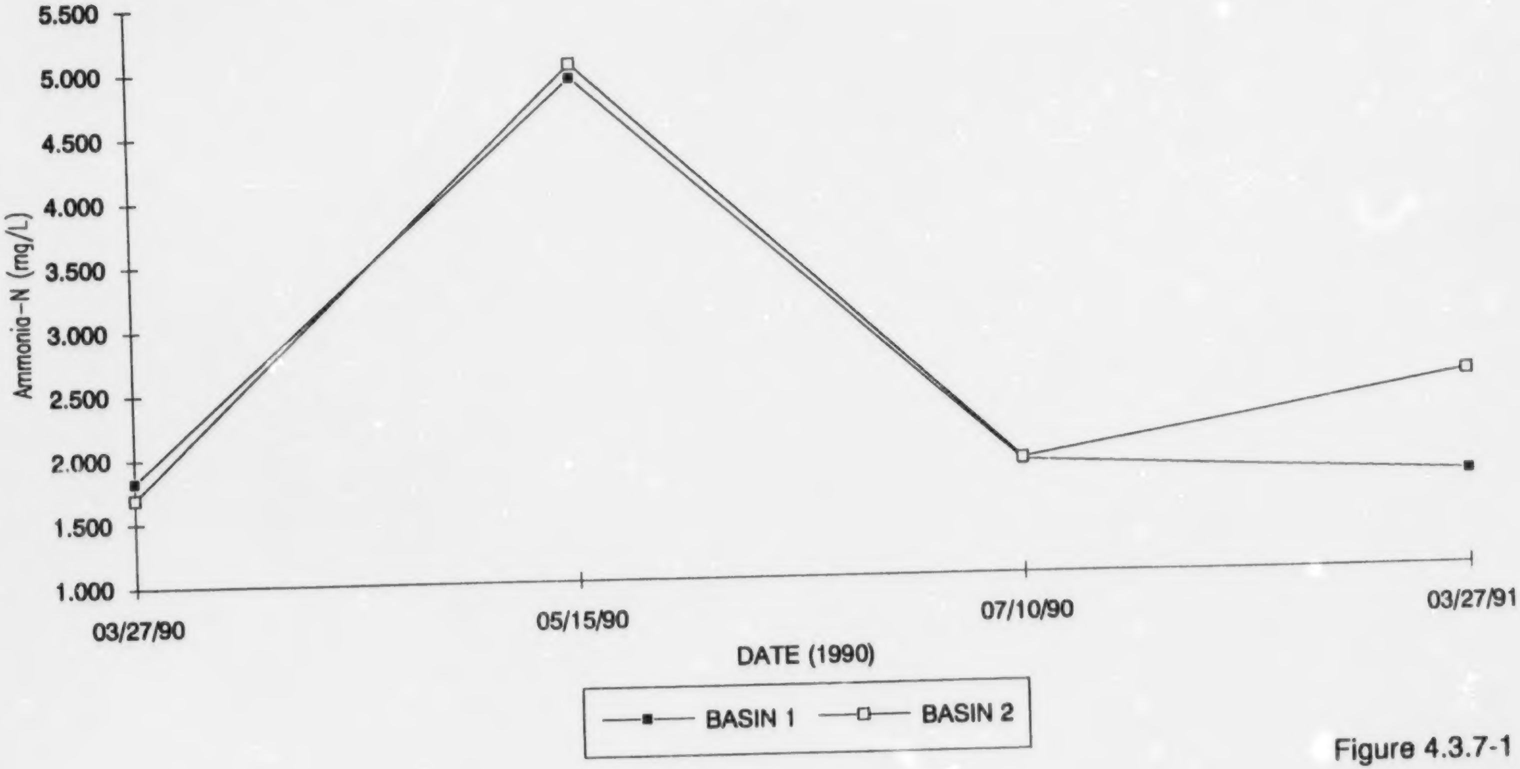


Figure 4.3.6-1



GROUNDWATER AMMONIA-N CONCENTRATIONS IN BASINS 1 AND 2
OF THE EXPERIMENTAL WETLAND 1990-1991

Figure 4.3.7-1

coupled with the absence of significant plant uptake during the early growing season. By mid summer 1990, groundwater NH_3 had declined to a level similar to the preceding March; the occurrence of this decline, despite the presumed concurrent increase in ammonification, suggests substantial ammonia removal by vegetation uptake and possibly other pathways (e.g., microbially mediated reduction to gaseous N_2). By late winter 1991, groundwater NH_3 concentrations in Basin 1 had declined slightly while those in Basin 2 increased. The difference between basins may reflect natural variability.

4.3.8 Nitrite

Average groundwater nitrite nitrogen (NO_2) concentrations were similar (0.005 mg/L in Basin 1 and 0.004 mg/L in Basin 2). Seasonal trends are shown in Figure 4.3.8-1. The highest concentrations (average 0.011 mg/L) were measured in late winter 1990. Values declined subsequently in both basins to near detection limits by mid summer 1990, presumably due to the NO_2 removal via denitrification. Between summer 1990 and late winter 1991, NO_2 in Basin 2 remained unchanged at the detection limit, while increasing to 0.004 mg/L in Basin 1. The increase in NO_2 in Basin 1 may reflect partial denitrification of influent NO_3, the addition of which had resumed in February 1991.

4.3.9 Total Phosphorus

Average total phosphorus (TP) concentrations in groundwater were 0.037 mg/L in Basin 1 and 0.061 mg/L on Basin 2, with an overall range of 0.030 to 0.088 mg/L in both basins. These values were higher than in surface waters, reflecting the P contribution from decomposing organic matter. Seasonal changes in TP are summarized in Figure 4.3.9-1. TP concentrations in late winter 1990 were similar in both basins, at approximately 0.004 mg/L, but diverged markedly thereafter. Values in Basin 1 declined slightly to 0.034 mg/L in spring and, by late winter 1991, had returned to the same level as in winter 1990. In Basin 2, TP increased slightly by spring, then more markedly to 0.088 mg/L by summer 1990, declining subsequently to 0.075 mg/L by late winter 1991. The trend in Basin 2 suggests that P release to groundwater increased during the growing season as a result of increasing mineralization of organic matter. The trend in Basin 1 suggests that what P was available in groundwater was removed during the early growing season, and that the rate of removal declined through the remainder of the growing season. It would thus appear that P uptake processes were dominant in Basin 1 whereas decomposition processes were dominant in Basin 2. The difference between basins may be attributable to the greater availability of N in Basin 1.

GROUNDWATER NITRITE-N CONCENTRATIONS IN BASINS 1 AND 2
OF THE EXPERIMENTAL WETLAND 1990-1991

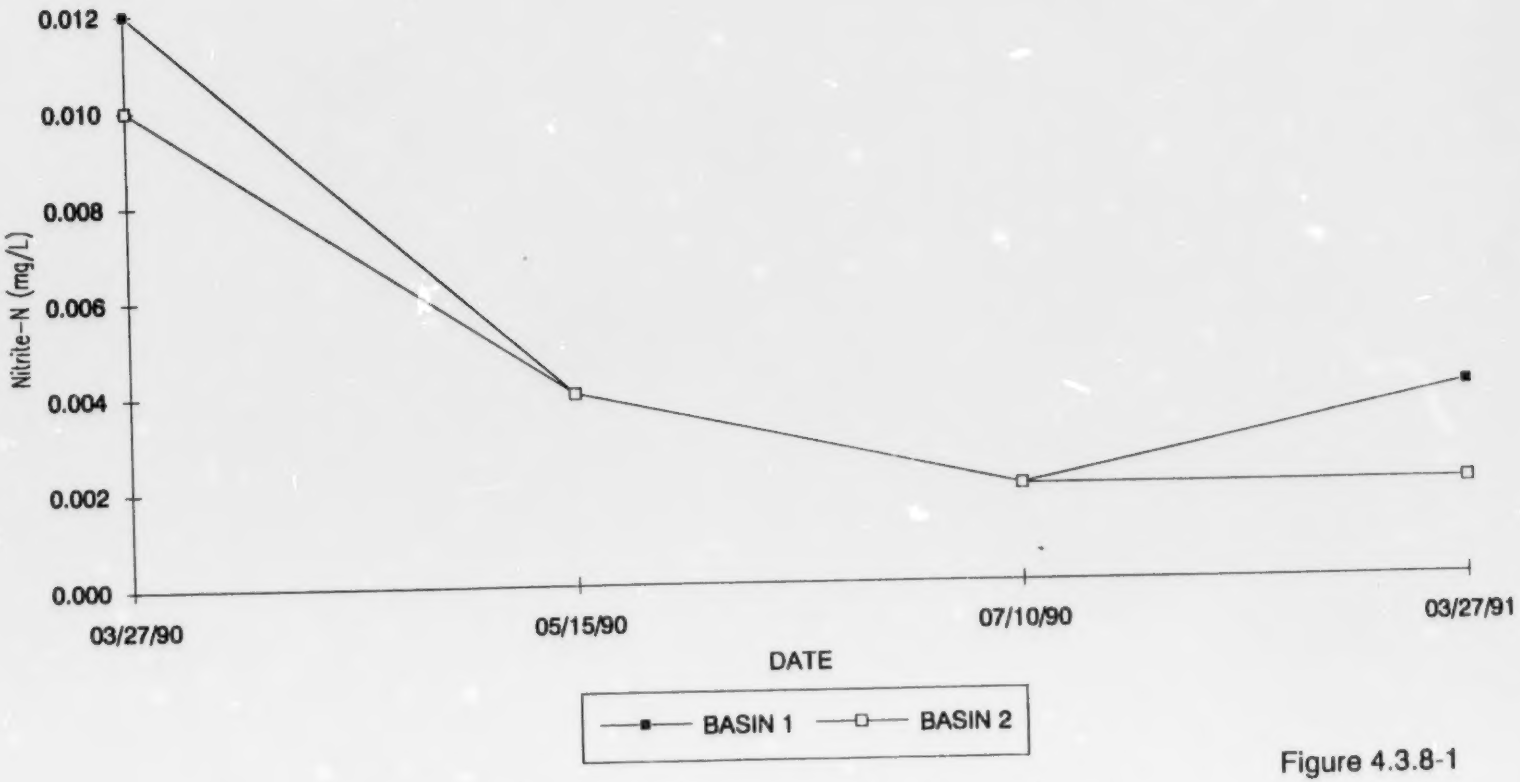


Figure 4.3.8-1

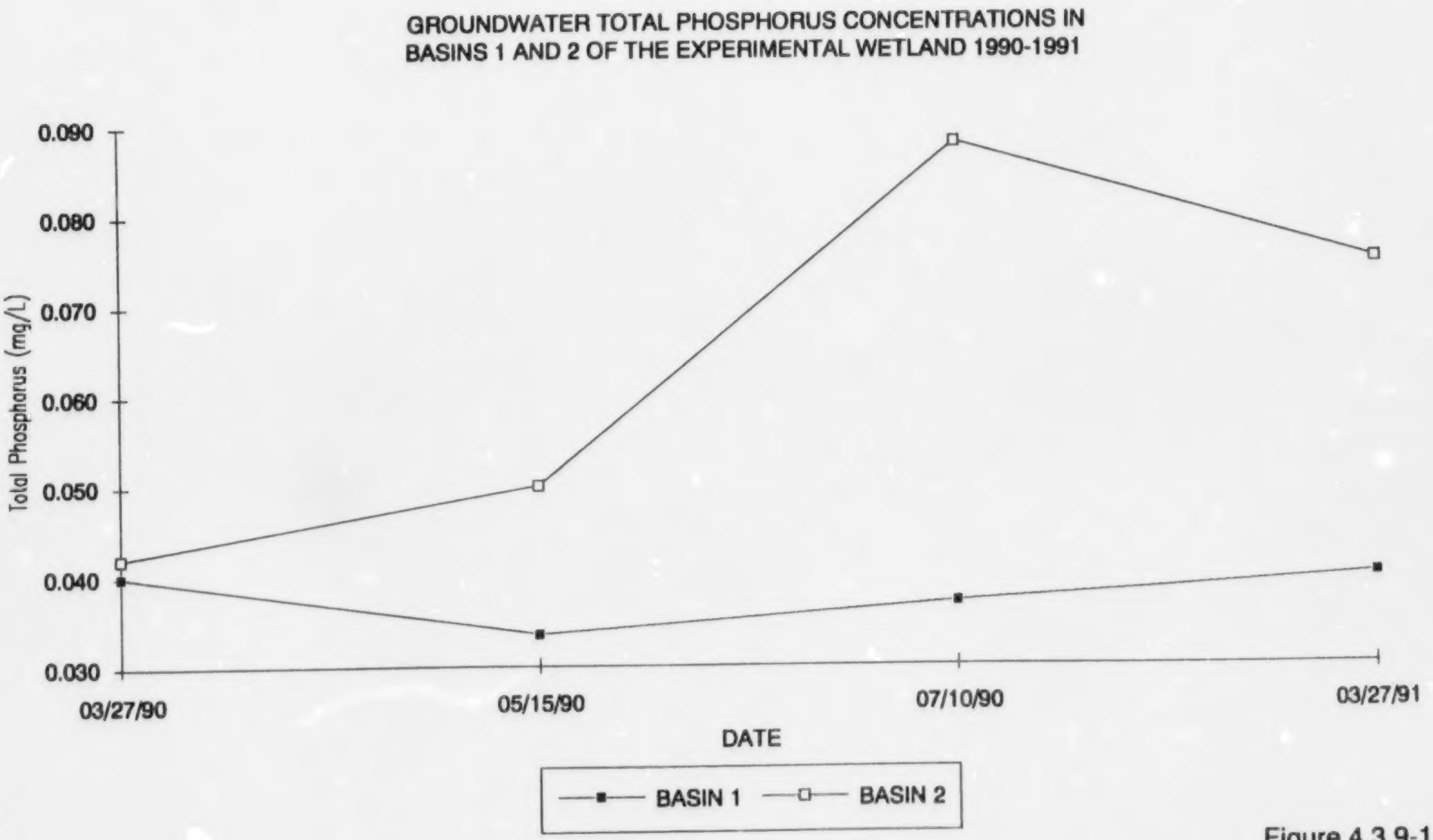

GROUNDWATER TOTAL PHOSPHORUS CONCENTRATIONS IN
BASINS 1 AND 2 OF THE EXPERIMENTAL WETLAND 1990-1991
Total Phosphorus (mg/L)
0.090
0.080
0.070
0.060
0.050
0.040
0.030
03/27/90
05/15/90
07/10/90
03/27/91
DATE
BASIN 1
BASIN 2

Figure 4.3.9-1

4.3.10 Total Dissolved Phosphorus

Data for total dissolved phosphorus (TDP) are available for late winter (March) 1990 only. The concentration of TDP on this occasion was 0.020 mg/L in Basin 1 and 0.013 mg/L in Basin 2; these values represent 50% and 31%, respectively, of the total P concentrations.

4.3.11 Orthophosphate (Bio-Available) Phosphorus

Data for orthophosphate phosphorus (PO_4) are available for late winter and spring 1990 only. Concentrations in both basins were consistently at the detection limit of 0.002 mg/L, representing at most 5% of total P. The bio-available fraction of P in groundwater was limited to at most 5% of total P and 15% of TDP and, therefore, most of the P in the wetland was bound in living or dead organic matter or adsorbed to exchange sites on mineral particles.

4.4 Vegetation

Data were obtained on vegetation composition and production in each of the experimental wetland basins. The following sections (4.4.1 and 4.4.2) describe the changes in vegetation composition over time, by species. Section 4.4.3 provides a discussion of plant matter productivity which is used as a basis for the nutrient mass balance for the experimental wetland.

4.4.1 Comparison Between Species

Cattail (*Typha latifolia*), sedge (*Carex sp.*) and sweetgale (*Myrica gale*) comprised the dominant emergent vegetation within the experimental wetland. Sweetgale was dominant in the natural wetland outside of the experimental enclosure, with sedge being sub-dominant. Mosses, grasses and other herbaceous species also occurred in lesser amounts.

Statistical analysis of vegetation mineral content was not attempted because of the reported very high natural variability.

Nitrogen

Figure 4.4.1-1 compares nitrogen content in above ground (shoot) and below-ground (root and rhizome) tissue among the three species. Data for cattail fruit, which were analyzed separately, are also shown. Tissue nitrogen content ranged from 2.13 % in cattail fruit to 0.87% in sweetgale root. N content ranking was as follows: cattail fruit > cattail shoot > cattail root > sweetgale shoot > sedge shoot > sedge root > sweetgale root.

NITROGEN CONTENT OF CATTAIL, SEDGE AND SWEETGALE FROM THE EXPERIMENTAL WETLAND
1990-1991

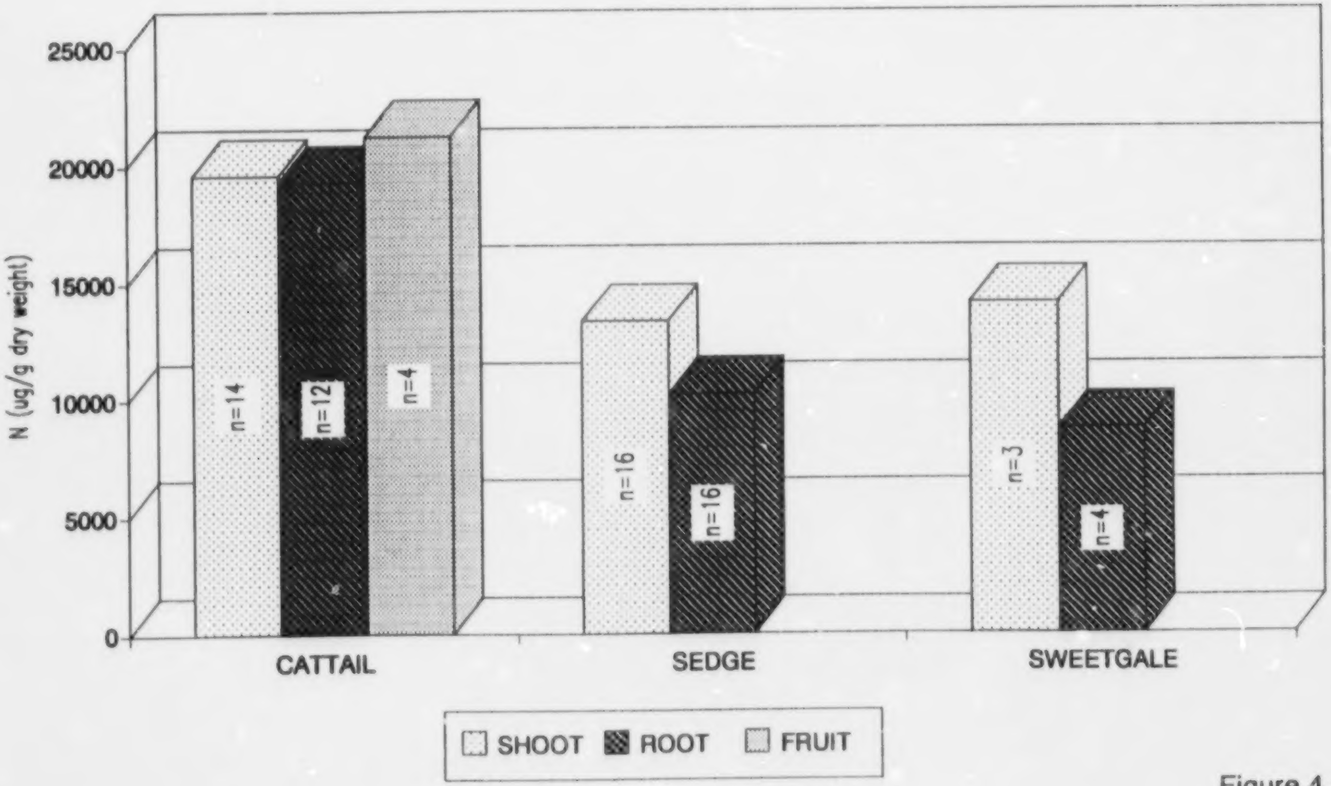


Figure 4.4.1-1

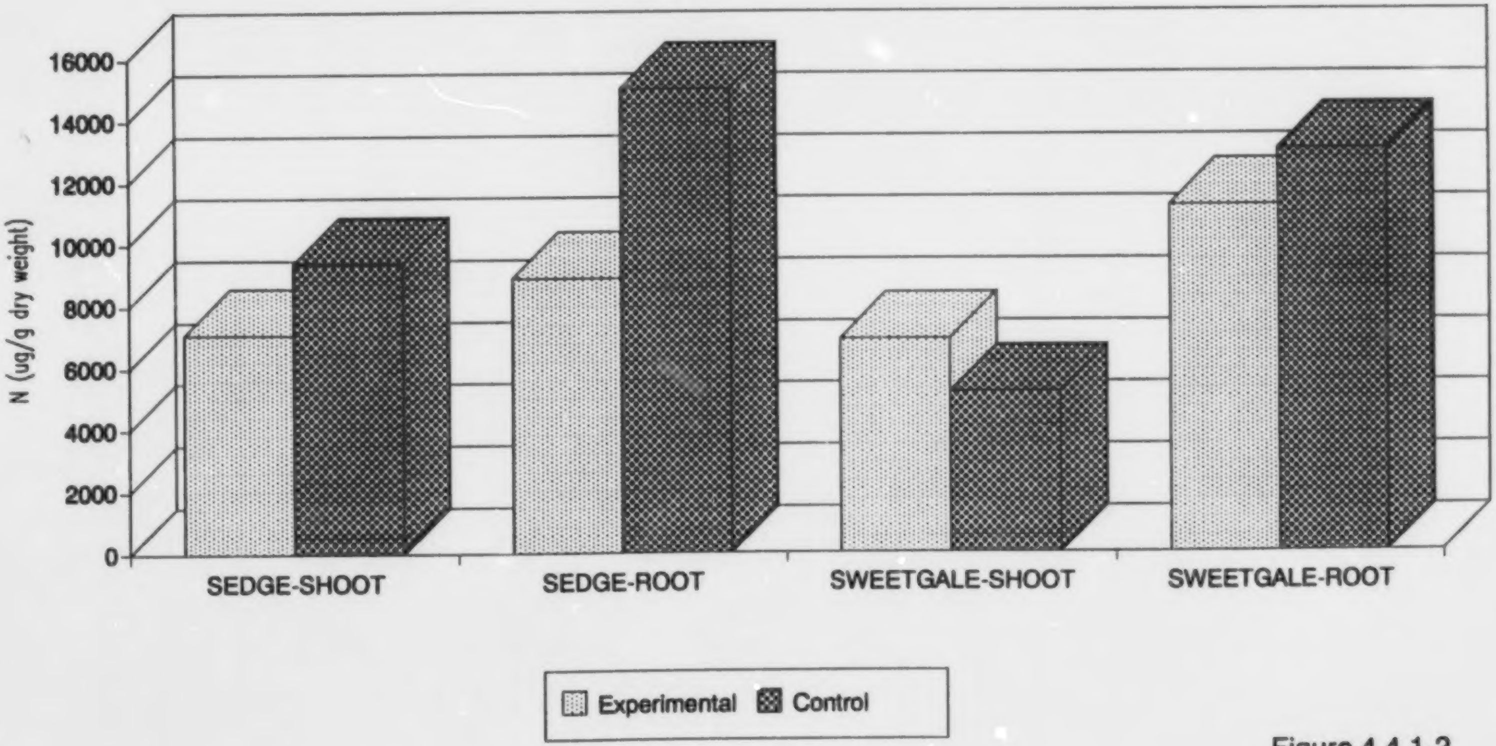
Figure 4.4.1-2 compares shoot and root N content in sedge and sweetgale between the experimental wetland and a control site in the adjacent natural wetland on March 27, 1991. (Cattail was not included in this comparison because the species is absent from the control site.) This sampling date represents late winter or early spring conditions when, except for nascent shoots, most of the above ground tissues are dead and the plants are beginning to break dormancy. Tissue N contents in sedge shoot, sedge root and sweetgale root were higher at the control site than in the experimental wetland, suggesting greater storage of N in plant tissues at the control site. Only sweetgale shoot tissue was higher in the nitrogen-enriched experimental wetland than in the control, suggesting an early translocation in sweetgale of N from the below-ground storage organs to the above-ground tissues or from the nitrate enriched water. Above-ground tissue N content was similar in sedge and sweetgale shoots collected from the experimental wetland, whereas the grass-like sedge shoot tissue from the control site contained substantially more N than did the more woody sweetgale tissue.

Figure 4.4.1-3 summarizes the seasonal changes in plant tissue N content. July 1990 data obtained on sedge shoot and root, and sweetgale shoot, are also included for comparison. N content in cattail shoot and root tissue was highest in early spring (April 1990), and generally declined through the remainder of the growing season as N stores in the rhizomes were depleted and as above ground N was distributed in a greater amount of biomass. A similar pattern was observed in the shoot tissues of sedge and sweetgale. Cattail root tissue N content increased between the summer (August 1990) and late winter (March 1991). This increase, which also occurred in sweetgale root tissue, reflects the translocation of N to below-ground storage organs at the end of the growing season.

Tissue N content in sedge shoot and root tissue showed an increase between July 1989 and April/May 1990 (Figure 4.4.1-3). The low shoot N content in summer reflects the "dilution" of N in the large living biomass, while the low root N content reflects the typical pre-storage condition, before N has been translocated to the roots from above ground tissues. The increase in tissue N content in sedge and sweetgale shoot tissues between July 1989 and April/May 1990 reflects both the high N content in growing leaves and the limited above-ground biomass in the plants before they have grown to full size at maturity in mid to late summer.

Phosphorus

Figure 4.4.1-4 summarizes the phosphorus (P) content in above-ground and below-ground plant tissues. Tissue P content ranged from 0.28% (2765 ug/g, dry matter basis) in cattail fruit to 436 ug/g in sweetgale root tissue. The overall ranking was cattail fruit > cattail shoot > cattail root > sedge shoot > sweetgale shoot > sedge root > sweetgale root. Tissue P content was consistently higher in shoot than in root tissue samples.



COMPARISON OF SEDGE AND SWEETGALE NITROGEN CONTENT FOR THE EXPERIMENTAL WETLAND AND THE CONTROL SITE - MARCH 27, 1991

Figure 4.4.1-2

SEASONAL CHANGES IN VEGETATION NITROGEN CONTENT
OF THE EXPERIMENTAL WETLAND 1989-1991

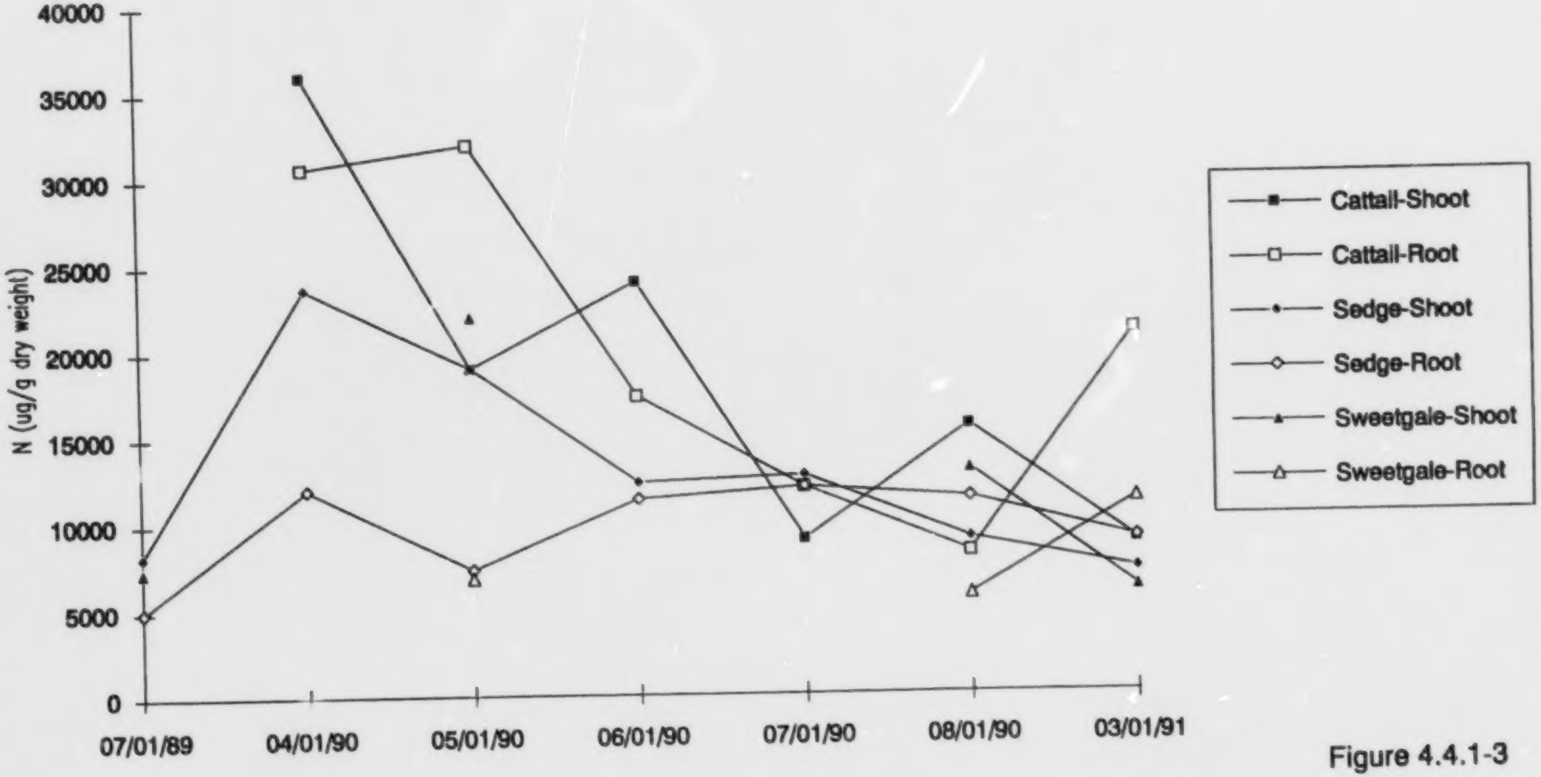


Figure 4.4.1-3

PHOSPHORUS CONTENT OF CATTAIL, SEDGE AND SWEETGALE
FROM THE EXPERIMENTAL WETLAND 1990-1991

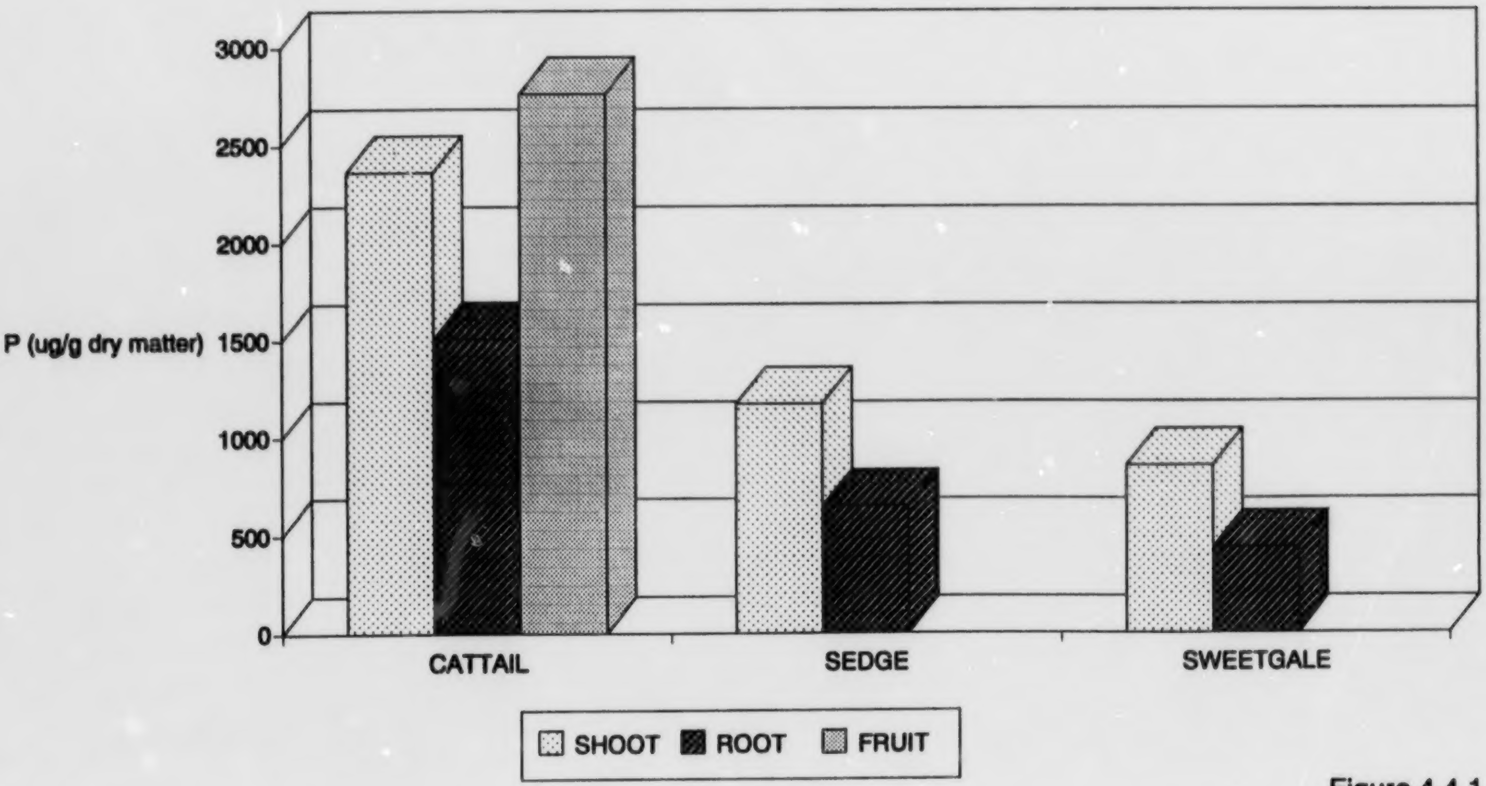


Figure 4.4.1-4

Figure 4.4.1-5 compares shoot and root tissue P content in sedge and sweetgale between the experimental wetland and a control site in the adjacent natural wetland on March 27, 1991. (Cattail was not included in this comparison because the species is absent from the control site.) This sampling date represents late winter or early spring conditions when, except for nascent shoots, most of the above ground tissues are dead and the plants are beginning to break dormancy. Tissue P contents in sedge shoot, sweetgale shoot and sweetgale root were higher in the experimental wetland than in the control. Only sedge root P content was higher in the control than in the experimental wetland. The greatest difference in tissue P content within species occurred with sweetgale, in which shoot tissue P content in the experimental system was 95.5% greater than the value in the control (430 ug/g versus 220 ug/g, respectively). The differences between sites for all the other samples were always less than 19.3%. It is evident that a substantial enrichment of sweetgale shoot P content occurred at this time of year in association exposure to high concentrations of nitrate N. The differences between species may be associated with species specific differences in phenology (that is, the timing of breaking of dormancy).

Figure 4.4.1-6 summarizes the seasonal changes in tissue P content of the three dominant plant species within the experimental wetland. As with N, sedge and sweetgale data from July 1989 are included for comparison. Cattail shoot and root tissue P content followed a decreasing trend from a maximum in spring (April 1990) to lowest values in the late growing season (July and August). Cattail tissue P content at the end of the following winter (March 1991) was similar to that in late summer, whereas root P increased again between August 1990 and March 1991. A similar pattern, though at lower concentrations, was followed by sedge and sweetgale shoot tissue (Figure 4.4.1-6). Phosphorous content in sedge root tissue tended to increase over the growing season to a maximum in late August; by the following March, P content had decreased to low levels. Sweetgale root data are more limited but show a maximum value in spring (May 1990) followed by steadily declining values through the 1990 growing season to a minimum at the end of the following winter (March 1991).

Although the trends of tissue P content are not as distinct as with N, the prevailing pattern reflects the translocation of P from the roots to the shoots in the early growing season, followed by concurrent dilution of above ground P in the expanding leafy biomass and translocation of P back to the roots for storage during the dormant season.

4.4.2 Implications with Respect to Harvesting for Nutrient Removal

The harvesting or cropping of above-ground plant tissues has been considered as a means of removing nutrients and other constituents from the wetland system used for wastewater treatment. The data on N and P obtained at Quinsam indicate that the highest concentrations of N and P in the harvestable biomass occur in the fresh

COMPARISON OF SEDGE AND SWEETGALE PHOSPHORUS CONTENT FOR THE EXPERIMENTAL WETLAND AND CONTROL SITE - MARCH 27, 1991

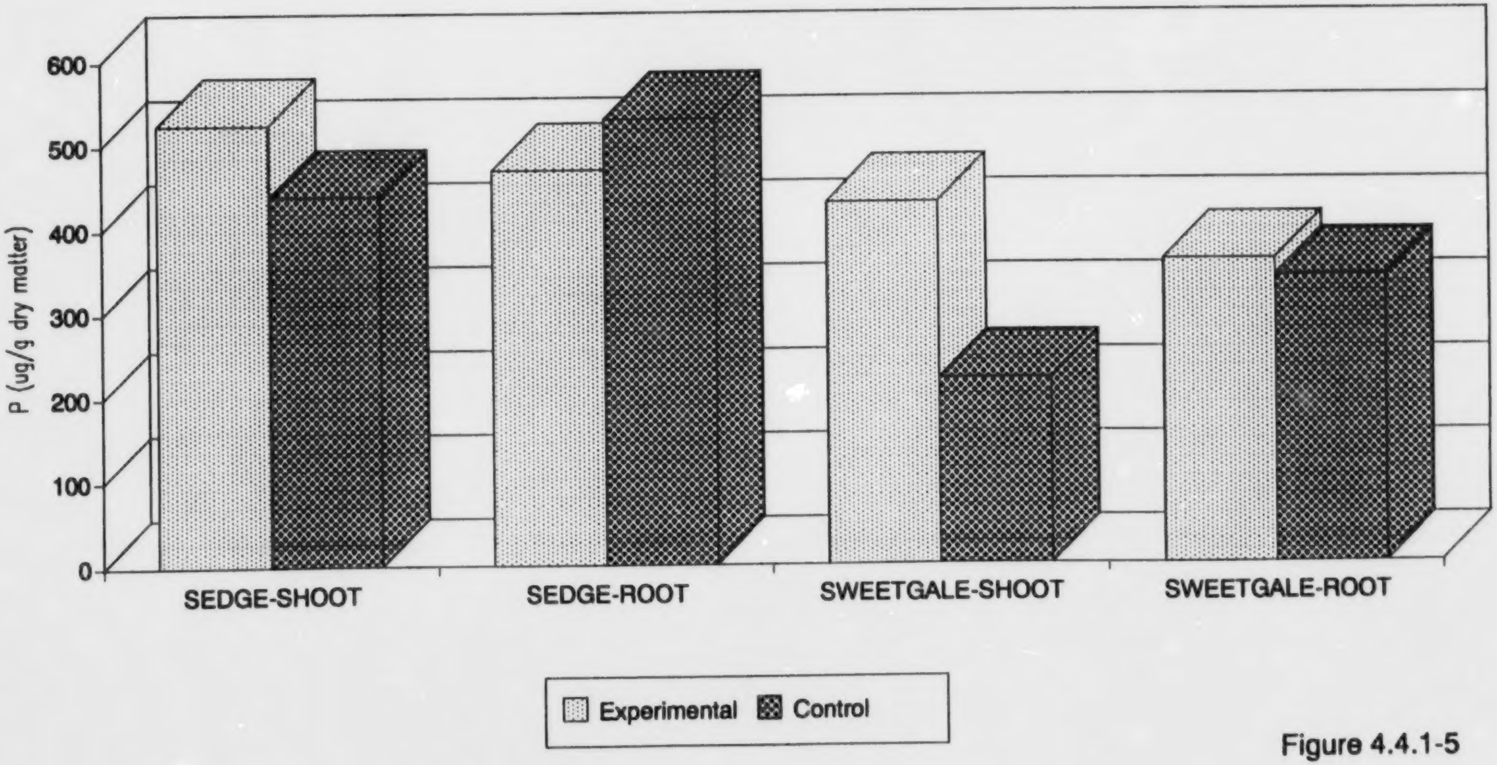


Figure 4.4.1-5

SEASONAL CHANGES IN VEGETATION PHOSPHORUS CONTENT
OF THE EXPERIMENTAL WETLAND 1990-1991

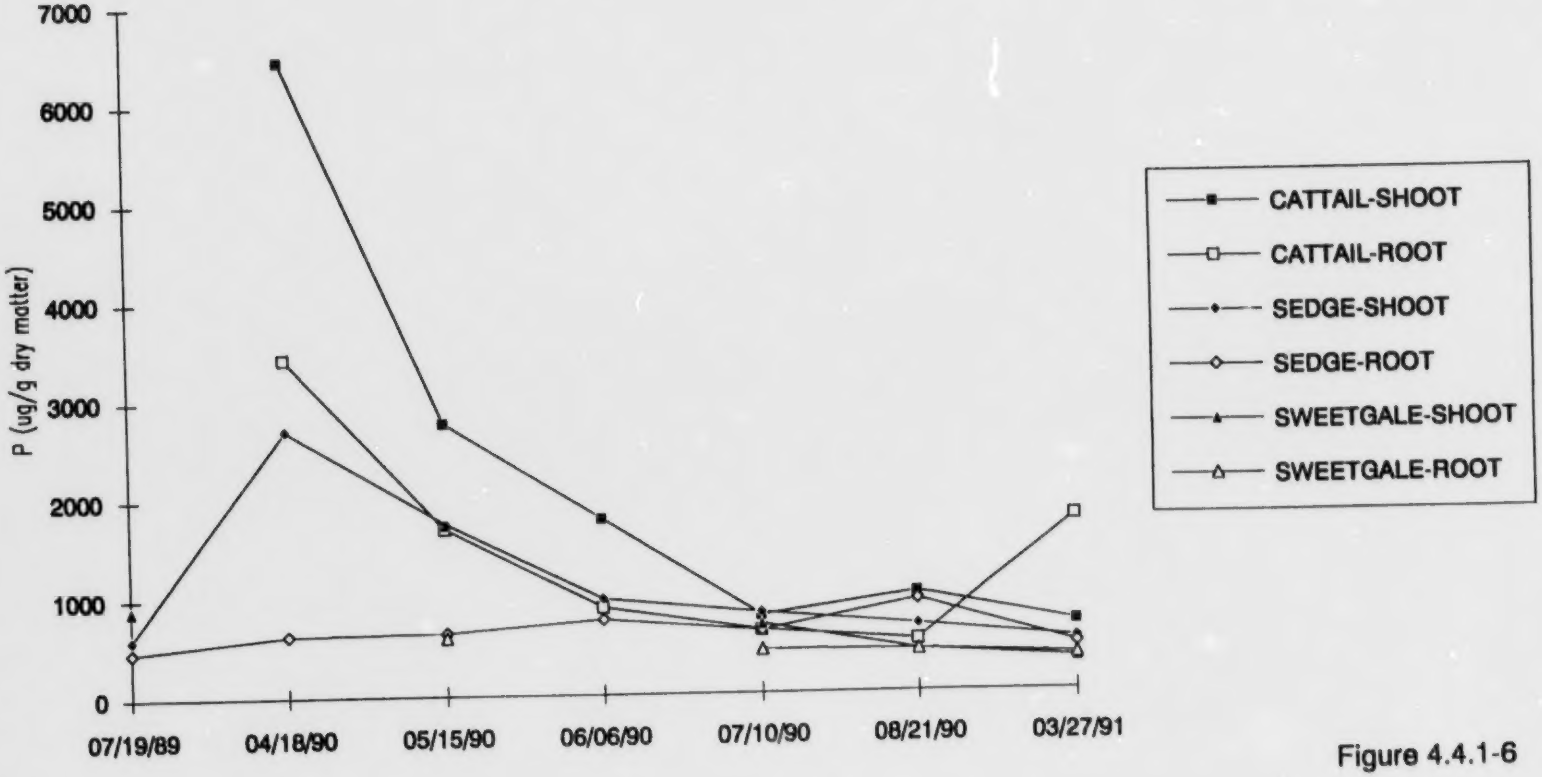


Figure 4.4.1-6

growth during spring. However, harvesting in spring would provide only a short term benefit. This is because the plants' nutrient reserves to support renewed growth may be limited, especially with respect to P and other micro-nutrients, and overall N or P removal into harvestable biomass may decrease on an annual basis. Thus, it appears that the harvesting of above-ground biomass cannot be maximized without potentially adverse effects on the vegetation. In view of the need to maintain a healthy root stock, it is probably best to harvest toward the end of the growing season, once nutrient storage in the roots has taken place but before the above ground biomass begins to break into fragments or be leached of its mineral content.

4.4.3 Biomass Productivity

Biomass production measured in the three 0.5 m by 0.5 m plots ranged from 268 g/m^2/year in the plot dominated by sweetgale, to 506 g/m^2/year in the plot dominated by cattail, and 971 g/m^2/year in the plot dominated by sedge. The site average was 582 g/m^2/year. Table 4.4.3-1 summarizes the nutrient and metal content of this above-ground biomass, based on annual average values obtained at the experimental site. The values shown in the table represent the amount of nutrients or metals which could be removed from the treatment system by harvesting annually the above-ground portion of vegetation. The data show that the herbaceous species, sedge and cattail, are preferable over the more woody sweetgale.

4.5 Surface Water Quality

Water quality data for samples collected between November 20, 1989 and March 31, 1991 are presented in this report. The reader is referred to the previous annual reports for data from Year 1 (Norecol 1989) and Year 2 (Norecol 1990) which covered the periods August 24 to December 5, 1988, and March 15 to November 6, 1989, respectively. Statistical significance analysis was performed for total Nitrogen only, as this was the central parameter of the study. The water quality data for the other parameters is available for future statistical analysis. A summary of water quality results obtained during Year 3 is provided in Appendix B-1.

In the discussion of water quality parameters that follows, the terms "influent", "midpoint" and "effluent" are used to describe the three sampling points in the experimental wetland (Figure 3.1-3). Influent means the nitrate enriched water that was piped to the experimental wetland from the dosing station and was discharged into the upper end of the upper wetland basin (Basin 1). Midpoint refers to the sampling point between the two basins, at the outlet weir from Basin 1. The midpoint is therefore the effluent from Basin 1 and the influent to the lower basin (Basin 2). Effluent refers to the discharge from Basin 2, and represents the final effluent of the experimental wetland.

TABLE 4.4.3-1

NUTRIENT AND HEAVY METAL CONTENT OF ANNUAL BIOMASS PRODUCTION IN THE EXPERIMENTAL WETLAND AT QUINSAM COAL MINE

1990 TO 1991

PARAMETER ($g/m^2/year$)	CATTAIL	SEDGE	SWEETGALE	SITE AVERAGE
Dry Matter	506	971	268	582
Nutrients				
N	9.9	13.0	3.8	8.9
P	1.2	1.1	0.23	0.86
Metals:				
Al	0.012	0.065	0.015	0.031
Cu	0.001	0.003	0.001	0.002
Fe	0.045	0.252	0.032	0.110
K	16	16	2	11
Mn	0.264	0.319	0.278	0.287
Zn	0.010	0.026	0.007	0.015

4.5.1 Temperature

The mean monthly temperatures recorded at the mine site are shown graphically in Figure 4.5.1-1. Mean temperatures above 10°C occurred between May and October, and summer means (June to September) were above 15°C. Daily maximum temperatures during the summer drought were commonly above 28°C.

4.5.2 Suspended solids

Suspended solids (SS) during Year 3 averaged 9 mg/L in the influent, 13 mg/L at the midpoint and 6 mg/L in the effluent. Variability in the influent and at the midpoint was quite high; coefficients of variation (C.V.) were 109% and 183%, respectively, compared to 34% in the effluent. Changes in SS concentration during Year 3 are shown in Figure 4.5.2-1.

Influent SS content was usually below 10 mg/L, although values of >15 mg/L (and a maximum of 62 mg/L) did occur, usually in association with peak rainfall events (especially in spring or fall/winter) or sampling difficulties due to presence of ice or snow.

Midpoint SS concentrations were also often below 10 mg/L, although values as high as 25 mg/L (and a maximum of 141 mg/L) occurred in winter and spring. The higher variability during the winter and spring probably reflected the increasing fragmentation of plant debris during the dormant season and possible contamination during sampling.

Effluent SS values were mostly below 7 mg/L, with occasionally higher values occurring in association with storm events in spring (March 1990 and 1991) and in fall (September 1990). The lower C.V. in the effluent indicates the effectiveness of SS removal in the wetland.

Whereas SS concentrations during Year 1 initially reflected the effects soil disturbance during construction of the experimental system, SS during Years 2 and 3 appears to have been correlated primarily with storm events.

4.5.3 Hydrogen Ion Concentration (pH)

Average pH during Year 3 was 7.7 in the influent, 7.5 at the midpoint and 7.5 in the effluent. The range at all three sites was the same: 6.9 to 8.3. Figure 4.5.3-1 shows the changes in pH over time. The difference between sampling sites was generally low during the winter of 1989 to 1990 (e.g., December 1989 to February 1990), with pH levels tending to decline from about 7.7 to 7.0. The difference increased during the growing season (e.g. March to June 1990), and remained pronounced until the end of the monitoring period in March 1991.

MEAN MONTHLY AMBIENT TEMPERATURE AT THE QUINSAM MINESITE FOR 1991

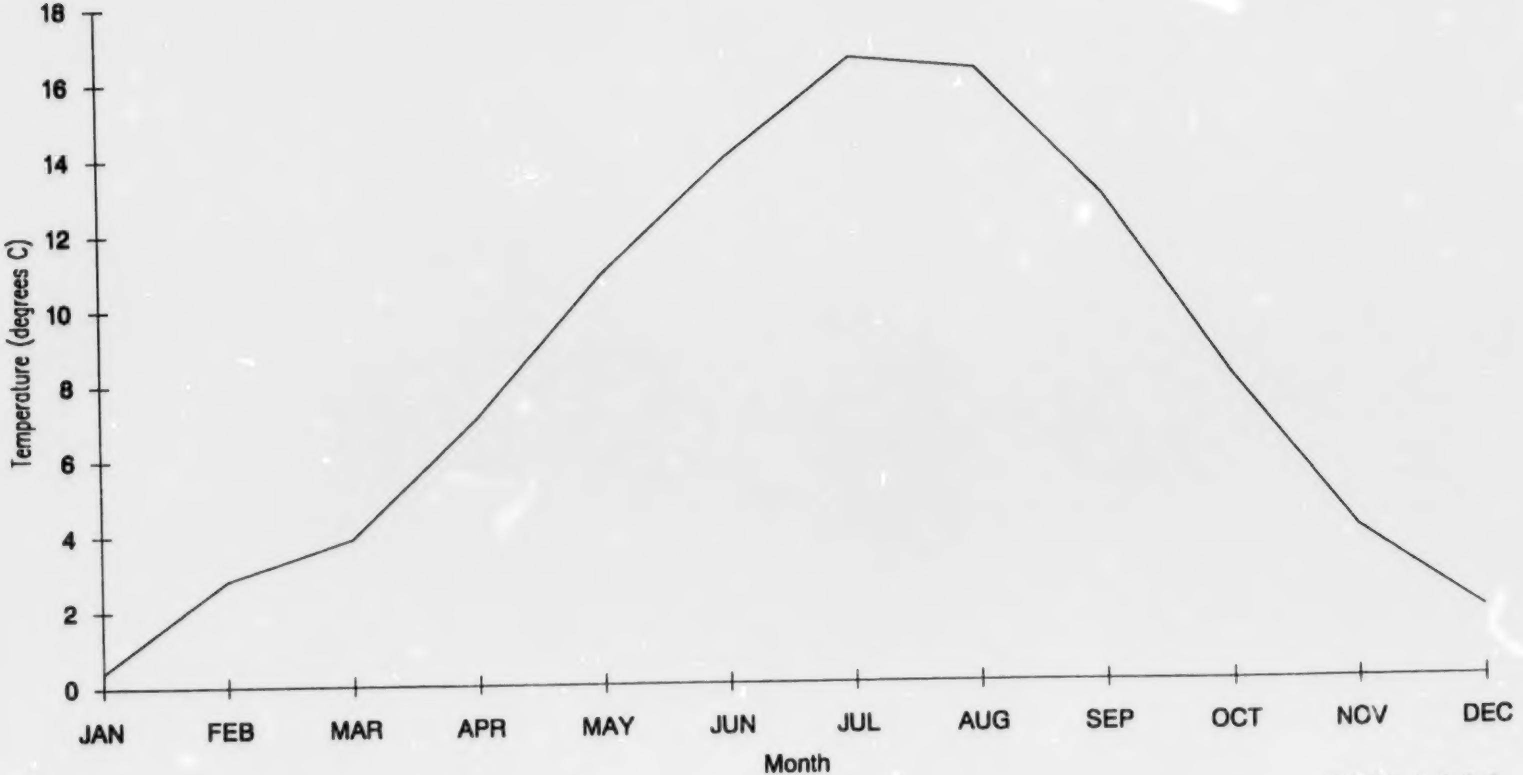


Figura 4.5.1-1

SUSPENDED SOLIDS CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989-1991

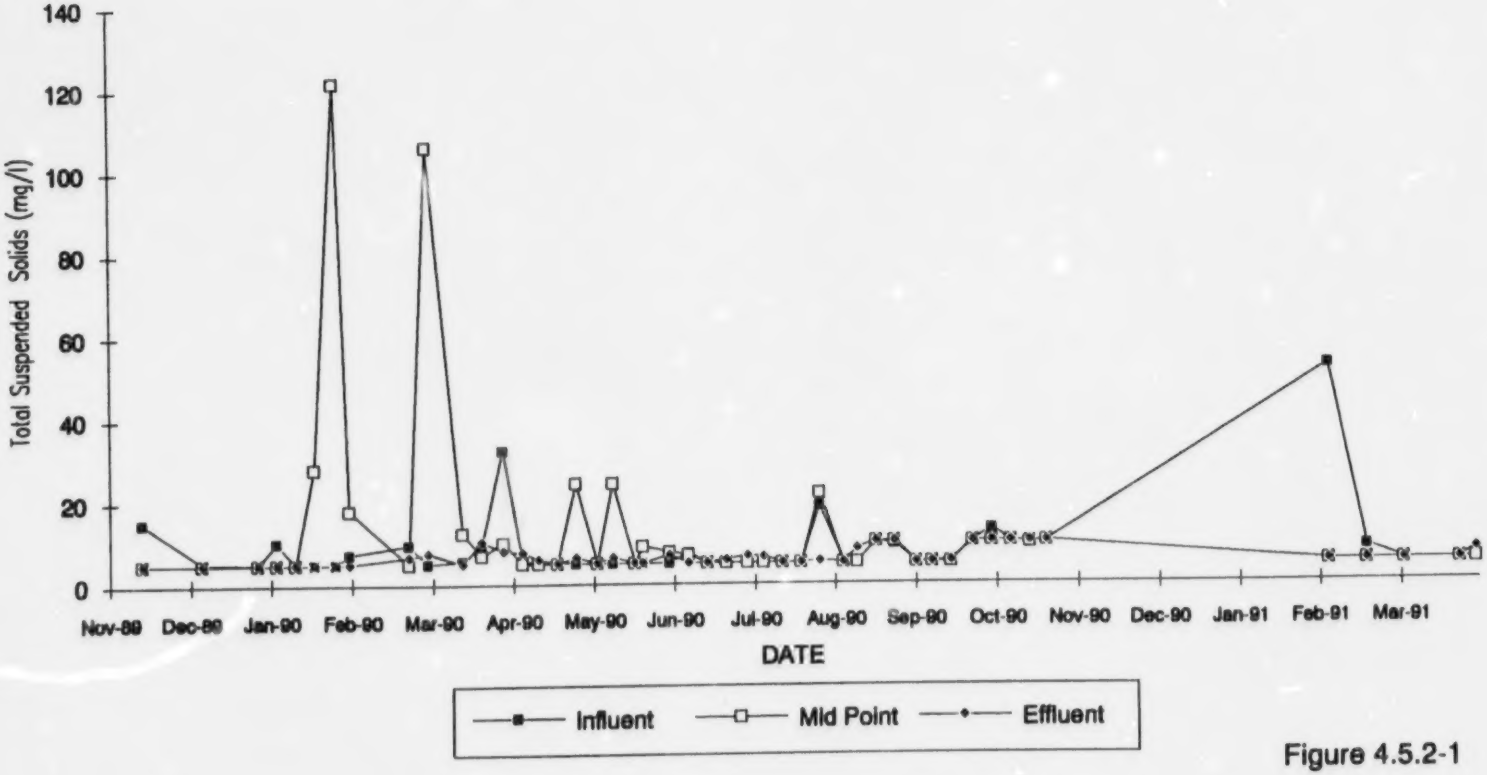


Figure 4.5.2-1

HYDROGEN ION CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND
EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

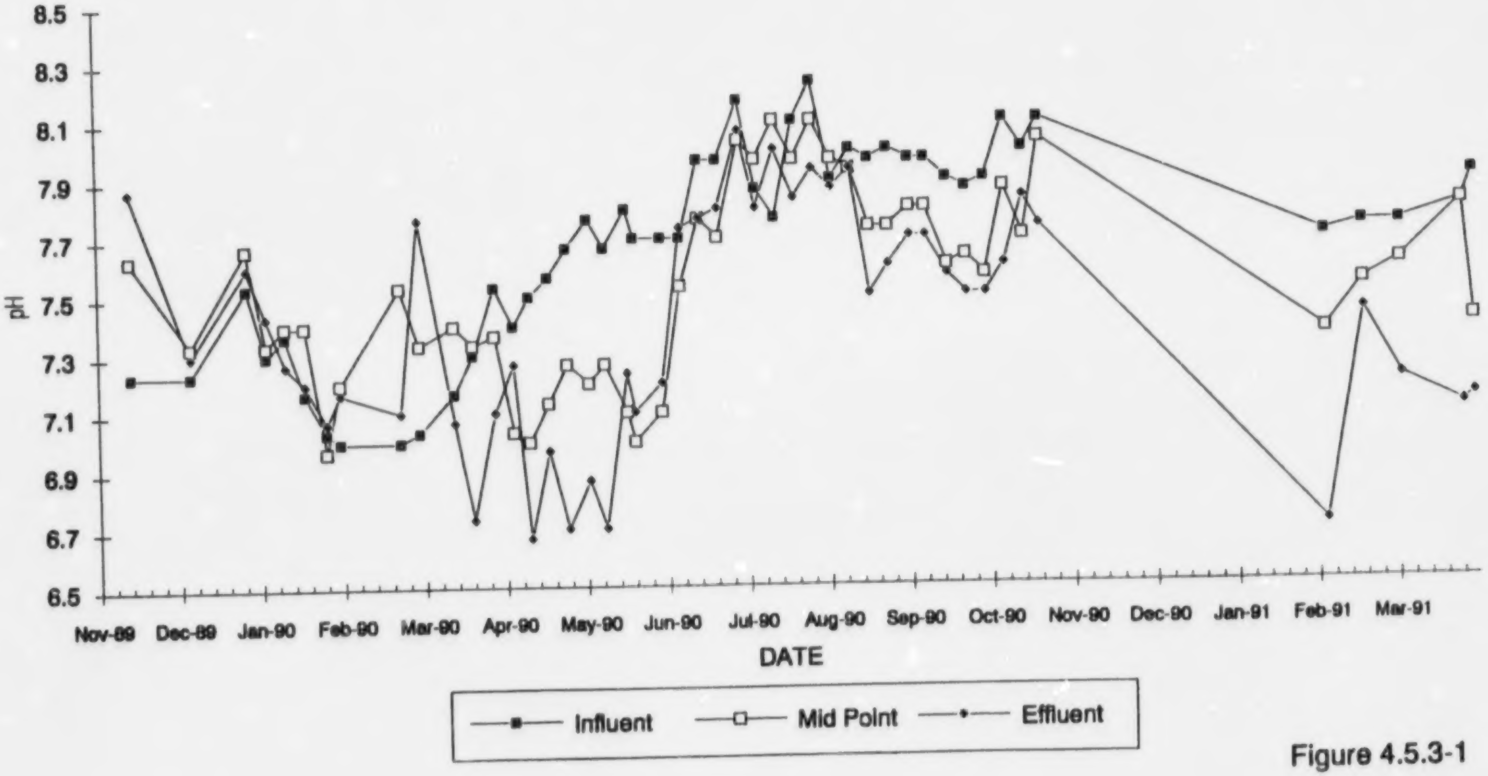


Figure 4.5.3-1

Influent pH levels tended to increase from about 7.1 in November 1989 to 8.2 by late July 1990, levelling off at 7.9 to 8.0 through until early October. After the resumption of the experiment in February 1991, influent pH tended to increase from 7.7 to 7.9 by the end of March. These influent pH levels show that the water in the mine settling pond was consistently neutral to slightly alkaline.

Midpoint levels remained lower, between 7.0 and 7.3 during March to early June 1990, then increased sharply in mid June, levelling off in the range of 7.7 to 8.1 during July, and subsequently declining to 7.6 by the early October 1990. On the resumption of monitoring in February 1991, midpoint pH was substantially lower than in the influent, increased markedly from 7.4 to 7.8 by late March, and dropped again to 7.5 by the end of March 1991.

Effluent pH levels during the early growing season were in the range of 6.7 to 7.3 and usually lower than at the midpoint. As in the midpoint samples, there was a sharp increase in effluent pH between late May and mid June, followed by a levelling off in the range of 7.7 to 8.1 during July and early August, usually at a slightly lower level than at the midpoint. After early August, effluent pH tended to decline, to 7.5 by early October. On resumption of monitoring in early February 1991, effluent pH was 6.7, much lower than at the midpoint, and rose sharply to 7.5 by late February, declining again to 7.2 by the end of the study in March 1991.

The pH data for Year 3, while remaining circum-neutral, show a trend of acidification within the wetland during the early growing season, followed by a marked alkalinization after mid June and acidification during fall and winter. The trend during the growing season probably reflects the effect of algal photosynthesis which, by removing dissolved CO_2, is known to cause a shift in the carbonate balance to alkaline levels (Ruttner 1963). The declines in early winter and late summer may reflect the release of organic acids from decomposing organic matter. The net effect is a seasonal fluctuation within the circum-neutral range of 6.9 to 8.3.

A similar pattern of pH levels occurred during the growing season (April to October 1989) in Year 2 (Norecol 1990). The trends during Years 2 and 3 were, however, different from that encountered between August and December 1989 during Year 1 (Norecol 1989). The similarity in pH results during Years 2 and 3 may indicate that the enclosed wetland system reached a steady state condition within one year.

4.5.4 Conductivity

Specific conductance during Year 3 averaged 1625 umhos/cm in the influent (range: 524 to 2720 umhos/cm), 1496 umhos/cm at the midpoint (range: 535 to 2610 umhos/cm), and 1367 umhos/cm in the effluent (range 333 to 2450 umhos/cm).

Variability within each sampling location was similar, with C.V. values of 40% to 45%. Figure 4.5.4-1 summarizes the changes in conductivity during Year 3.

The influent usually had the highest conductivity, followed by the midpoint and the effluent. All sites followed a parallel trend of increasing conductivity during the growing season, with occasional lows in association with dilution by rainfall events (for example in June 1990, Figure 4.5.4-1). The steep rise in conductivity in February 1991 reflects the resumption of dosing with the KNO_3 after the experiment was interrupted between November 1990 and January 1991.

Influent conductivity values during Years 1 and 2 ranged from 400 to 950 umhos/cm, and from 600 to 1900 umhos/cm, respectively. While the low end of the range is similar to Year 3, an increase has occurred at the high end of the range. This increase may reflect the progression of mine development, possibly coupled with the evaporative concentration of dissolved substances in the mine settling pond during the summer drought periods.

Midpoint conductivity values ranged from 117 to 794 umhos/cm during Year 1 and from 600 to 6280 umhos/cm during Year 2. Values during Year 3 were intermediate between those of Years 1 and 2. The overall decline between Years 2 and 3 may reflect the lower KNO_3 dosing concentrations in Year 3.

Effluent conductivity levels during Year 1 ranged from 151 to 680 umhos/cm, and during Year 2 from 169 to 1180 umhos/cm. Values during Year 3 were generally higher, possibly reflecting an overall increase in mineralization of organic matter (and the resultant release of dissolved substances into solution).

The data obtained over the three year study show that, with a few exceptions related to precipitation events, there was a decrease in conductivity as the water passed through each basin of the experimental wetland.

4.5.5 Dissolved Organic Carbon

Figure 4.5.5-1 shows the changes in dissolved organic carbon (DOC) between November 1989 and March 1991. Average DOC concentrations were 7.9 mg/L in the influent (range: 3 to 44 mg/L) and 8.7 mg/L at the midpoint and the outlet (ranges: 3 to 54 and 3 to 20 mg/L, respectively). Variability was highest in the influent and midpoint samples (C.V. = 93% and 99%, respectively) compared to the effluent (C.V. = 41%).

Ranking of concentrations within sampling dates showed that there was usually an increase in DOC as the water passed through the wetland. Exceptions to this pattern occurred in conjunction with rainfall events (e.g., Figure 4.5.5-1, December 12, 1989) or with the onset of warm weather and related increases in decomposition of organic matter (e.g., April 10, 1990).

SPECIFIC CONDUCTANCE IN THE INFLUENT, MIDPOINT AND EFFLUENT
OF THE EXPERIMENTAL WETLAND 1989-1991

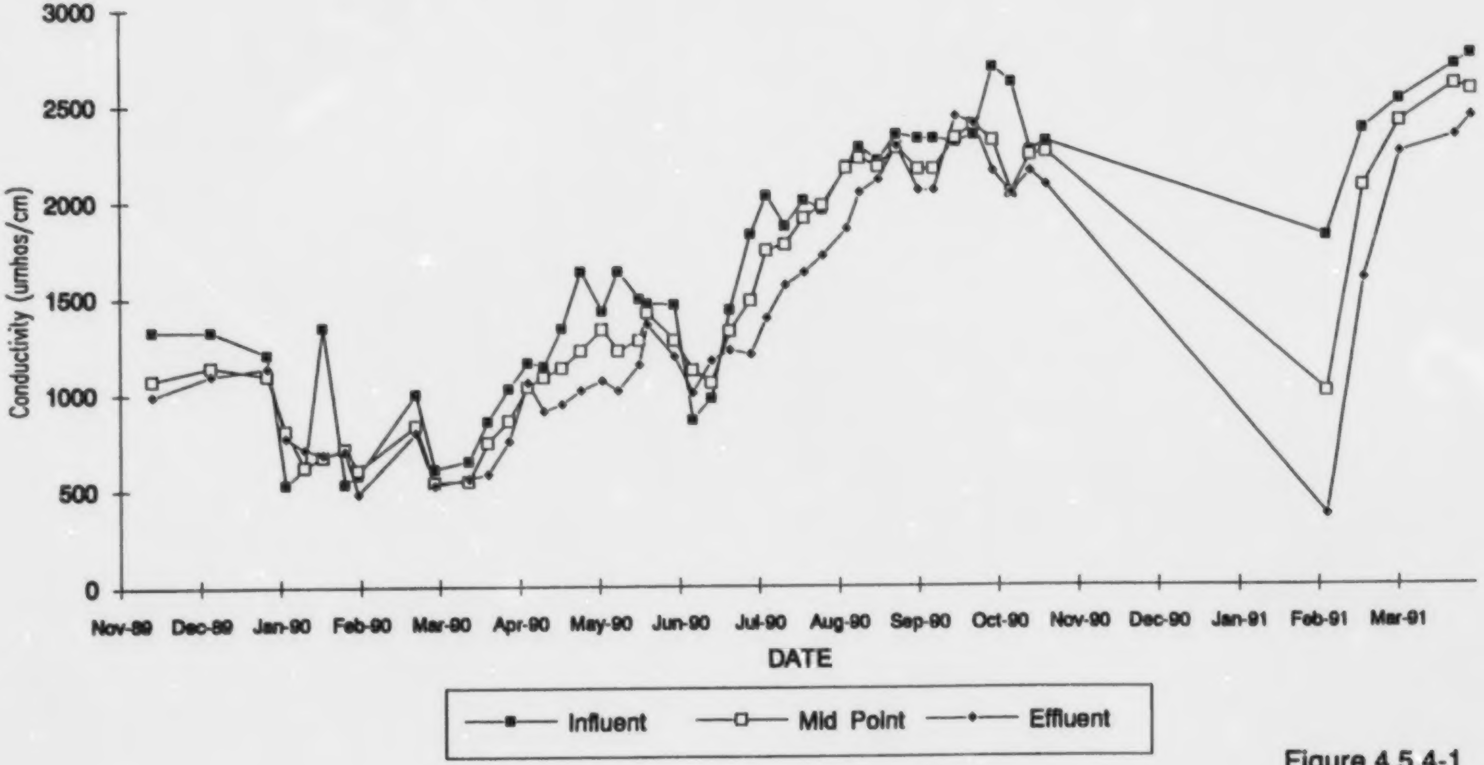


Figure 4.5.4-1

DISSOLVED ORGANIC CARBON CONCENTREATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989-1991

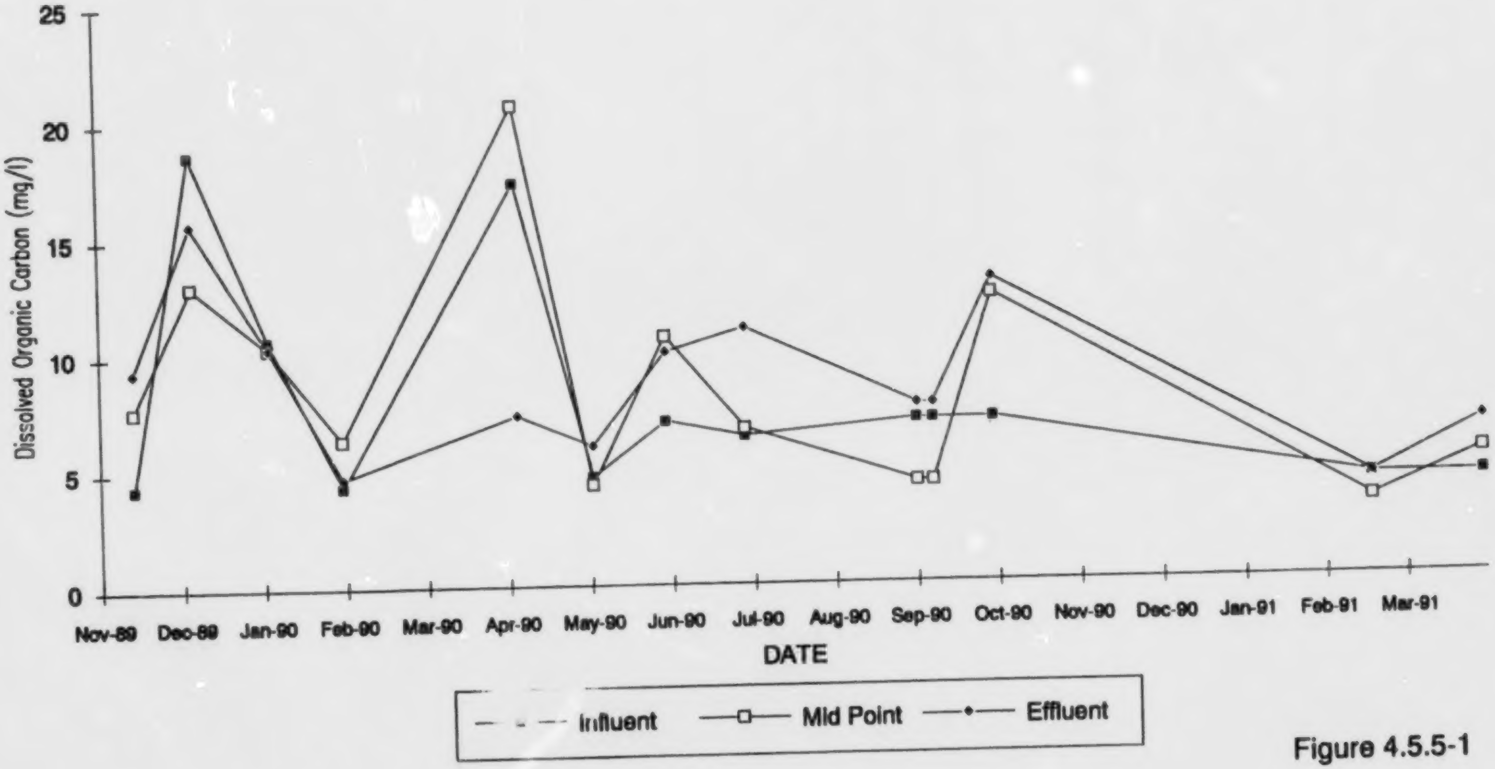


Figure 4.5.5-1

Whereas total organic carbon (TOC) was measured during Year 1 (Norecol 1989), DOC was measured during Year 3 to gain some understanding of the removal of non-particulate organic matter. During Year 1 the wetland exported total organic carbon during the late growing season and became a TOC sink after late September, whereas during Year 3 DOC was generally exported. Comparison of the DOC and TOC values showed the range of organic carbon values obtained during Years 1 and 3 were similar and, that the particulate fraction of TOC was very low (that is, DOC was usually equal to TOC). These results indicate that the organic carbon removed during the fall in Year 1 was probably in particulate form.

The results of the study indicate that removal of organic carbon in the wetland system was probably limited to particulate organic carbon and that the wetland acted as a source of dissolved organic carbon throughout the year.

4.5.6 Nitrogen

All concentration values in this section are reported as mg/L of elemental nitrogen (N), to facilitate the mass balance calculations presented in Section 4.6. Nitrogen species data summary tables are included in Appendix B-1.

Ammonia Nitrogen

Average total ammonia nitrogen $(NH_4^+ + NH_3)$-N concentrations during Year 3 were 0.155 mg/L in the influent (range 0.002 to 0.444 mg/L), 0.097 mg/L in the midpoint samples (range: 0.002 to 0.900 mg/L) and 0.093 mg/L (0.002 to 0.610 mg/L). Figure 4.5.6-1 summarizes the changes in ammonia concentration between December 12, 1989 and March 31, 1991. The seasonal trends shown by the data indicate that the wetland tended to be a sink for ammonia during the summer and early fall (June through October) and to export ammonia during the late fall through late spring (November through May).

During Years 1 and 2, ammonia was exported from the wetland throughout the year, albeit at low concentrations (Norecol 1989, 1990). Year 1 was the post-construction period during which ammonia releases due to recent disturbance and accelerated decomposition rates could be anticipated. During Year 2, export of ammonia was probably due to the elevated influent nitrate concentrations that were maintained. The data for the three year period suggest that the wetland may have attained during its third growing season a condition of biological maturity, in that the uptake and reduction of ammonia during the growing season actually exceeded ammonia releases through decomposition of organic matter.

TOTAL AMMONIA-N CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

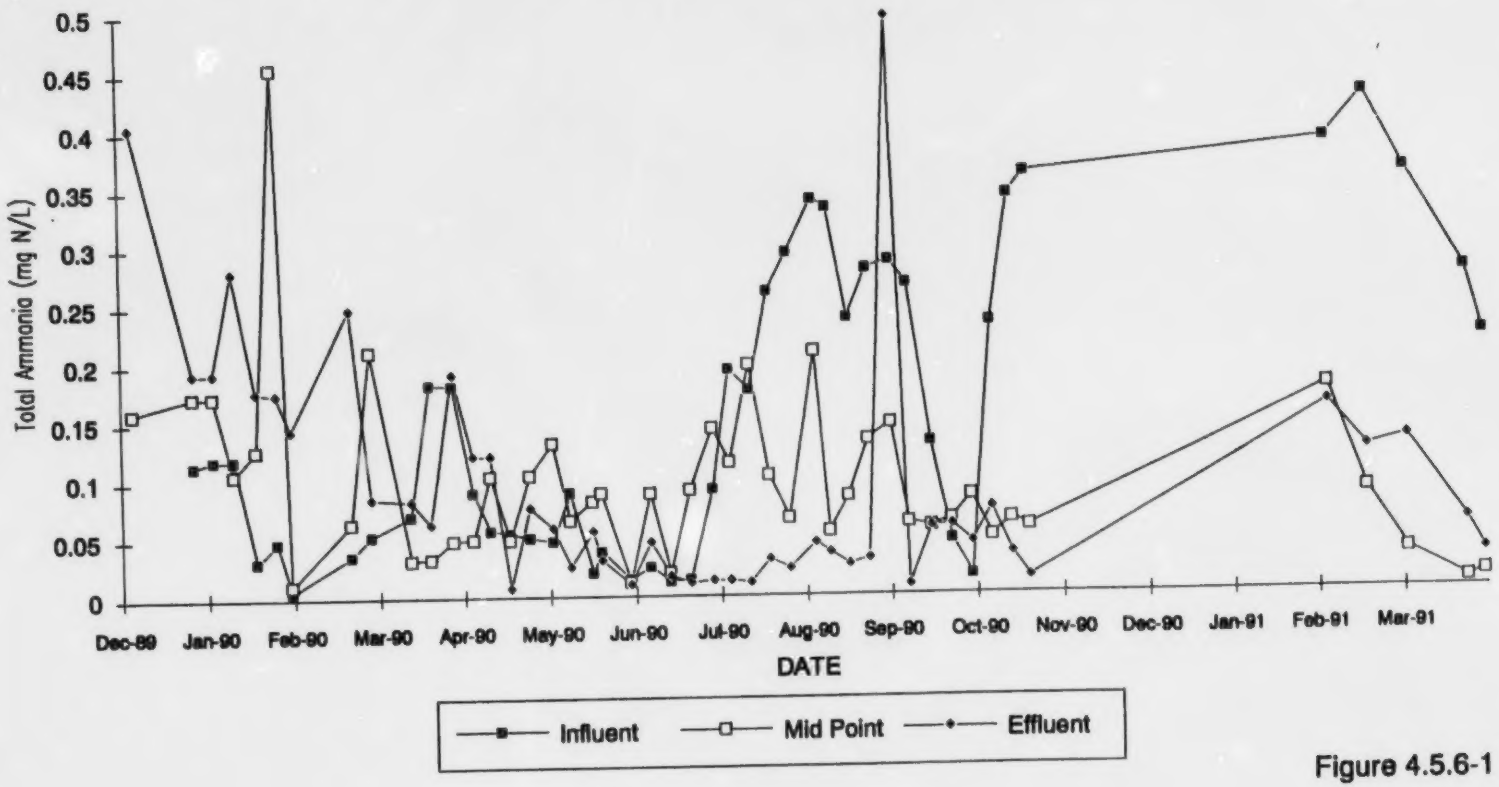


Figure 4.5.6-1

Nitrite Nitrogen

Nitrite nitrogen concentrations during Year 3 averaged 0.025 mg/L in the influent, 0.017 mg/L at the midpoint and 0.020 mg/L in the effluent. The variability during Year 3 was high, with C.V. values in excess of 88%. Figure 4.5.6-2 shows the changes in nitrite concentration between November 20, 1989 and March 31, 1991. Influent NO_2 levels during winter 1989 to 1990 were consistently lower than at the midpoint and effluent. Midpoint and effluent NO_2 during this period were variable, with effluent values less or greater than at the midpoint. With the onset of warmer temperatures in March 1990, midpoint NO_2 concentrations tended to become lower than in the influent and levels in the effluent tended to be lower than at the midpoint. With some exceptions, this pattern persisted throughout the remainder of the 1990 growing season (April through October). Increases in nitrite concentrations at the outlets of either wetland basin were associated with rainfall events or with exceptionally high influent nitrate concentrations (see next subsection).

The reductions in NO_2 concentration reflect denitrification and, during precipitation events, dilution. The increases in NO_2 reflect incomplete denitrification of higher influent NO_3 concentrations, and/or flushing (reduced retention time) during major rainfalls.

Nitrate Nitrogen

Nitrate nitrogen (NO_3) during Year 3 averaged 14.8 mg/L (range: 0.140 to 46.6 mg/L) in the influent, 5.0 mg/L at the midpoint (range: 0.001 to 18 mg/L) and 2.6 mg/L (range: 0.001 to 12.6 mg/L) in the effluent. Figure 4.5.6-3 shows the changes in nitrate concentration between November 20, 1989 and March 31, 1991.

Influent nitrate concentrations until late February 1990 were usually above 20 mg/L, reflecting the higher nitrate dosing rate that was being applied during Year 2 (Norecol 1990). The selected dosing rate was reduced at the start of Year 3 to produce an influent nitrate concentration within the nominal range of 10 to 15 mg/L. Most of the influent NO_3 values during the remainder of Year 3 were within this range, although excursions from the desired range occurred on 12 out of the 37 weekly sampling events during Year 3 (April 1, 1990 through March 31, 1991). Excursions from the desired range were due to temporary operational or mechanical problems with the dosing system: the low values were due to either an empty dosing barrel or pump failure (discharged battery) at the time of sampling; and the high values were attributable to an excessively concentrated batch of KNO_3 stock solution, or high pumping rate.

Midpoint nitrate concentrations between November 1989 and March 1990 (i.e. winter 89/90) were consistently lower than in the influent, and tended to decrease from approximately 17 to 8 mg/L during this period despite influent concentrations of 20

NITRITE-N CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

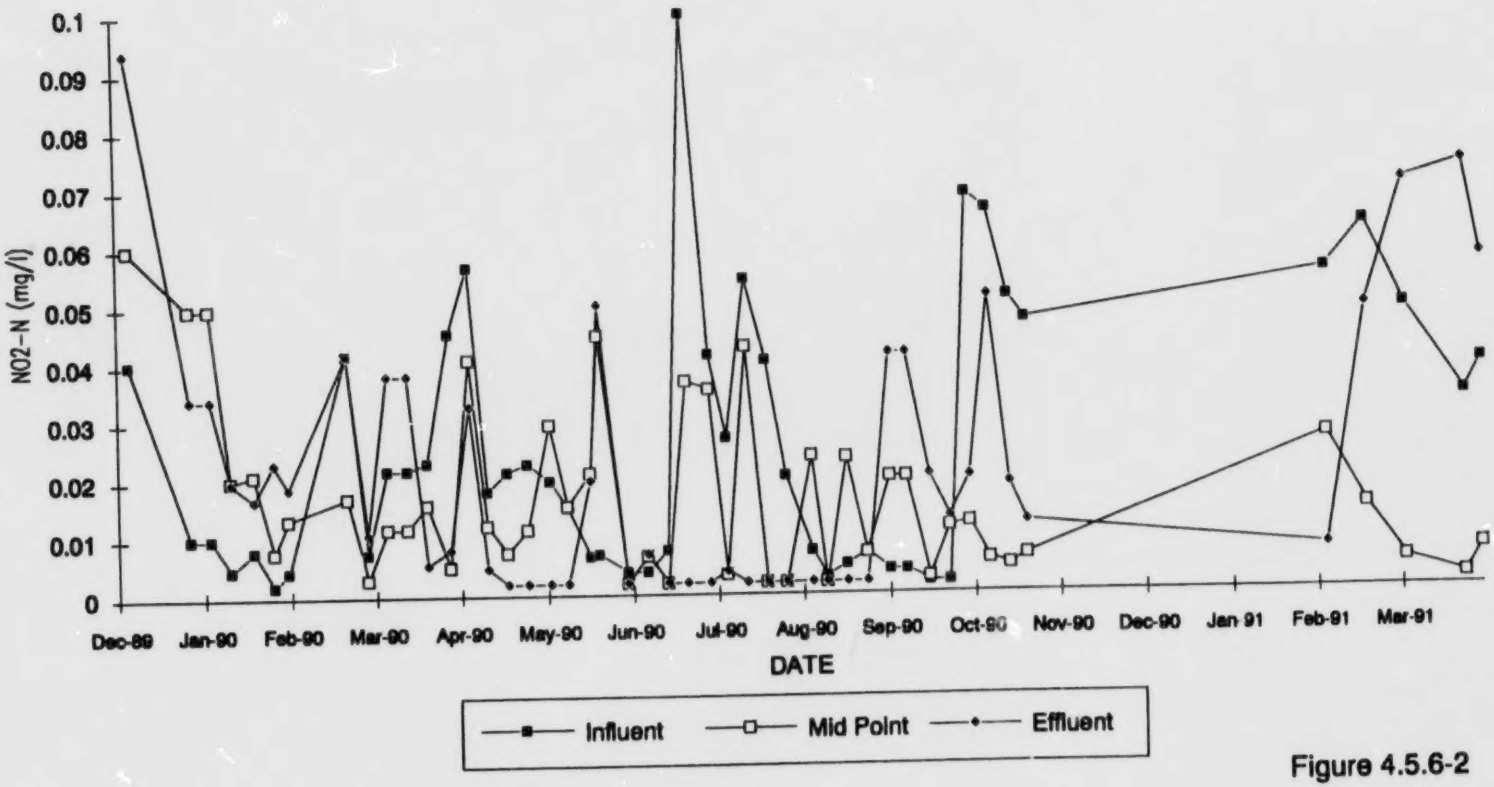
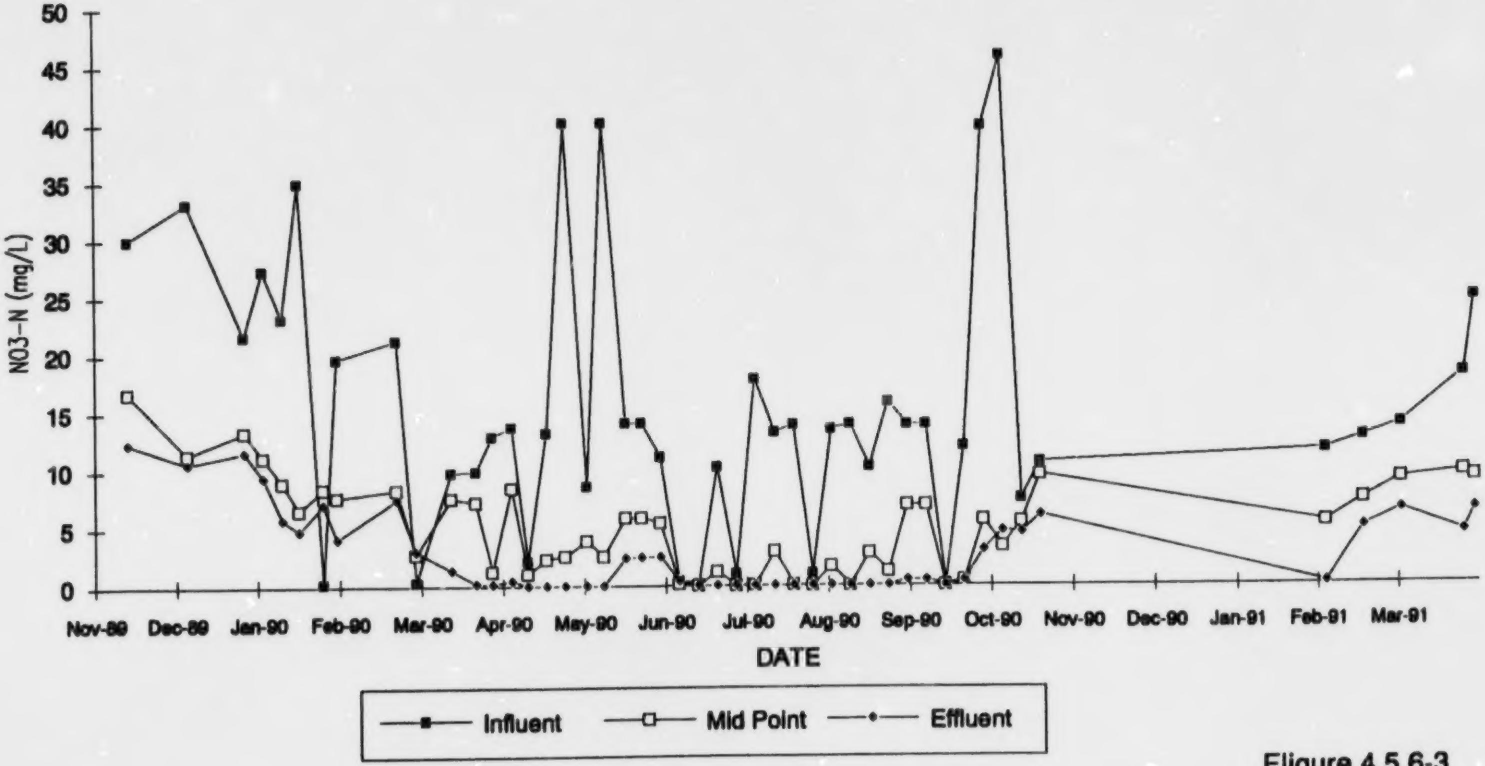


Figure 4.5.6-2

NITRATE-N CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991



Fligure 4.5.6-3

to 35 mg/L (Figure 4.5.6-3). During the remainder of the 1990 to 1991 monitoring period, midpoint NO_3 was consistently intermediate between influent and effluent NO_3 concentrations, with peak and low values occurring in association with high or low influent concentrations, respectively. The NO_3 concentration differential between the influent and midpoint tended to increase during the growing season and decrease with the onset of cooler weather in the fall. When the project was resumed during winter conditions in early February, midpoint NO_3, although lower than influent levels, tended to increase with rising influent NO_3 concentrations. The concentration differential remained constant during cold weather in February and early March 1991, but increased in late March with the onset of warmer weather and heavy rainfall.

Effluent NO_3 was consistently lower than at the midpoint, although the differential between these two locations was considerably less than between the influent and the midpoint. Between November 1989 and March 1989 (winter 89/90), effluent NO_3 closely parallelled the midpoint concentrations (Figure 4.5.6-3), with the differential being usually less than 4 mg/L. Values in the effluent during most of the ensuing growing season were at or below the 0.002 mg/L NO_3 detection limit. Exceptions occurred during late May as a result of exceptionally high influent NO_3 loading, and in early September, when the wetland was flushed by the first rainfall after almost two months of drought (Figure 4.1.2-1). The difference between effluent and midpoint NO_3 concentrations during this period, while usually less than 5 mg/L, tended to decrease over time. Between early September and the cessation of monitoring in late October, effluent NO_3 concentrations increased, in response to both cooler temperatures and high nitrate loading to the experimental wetland. The differential between the effluent and midpoint during this fall period was often negligible. After resumption of monitoring in early February 1991, effluent NO_3 paralleled the rising concentrations at the midpoint, dropping again in late March as a result of dilution by heavy rainfall (Figure 4.1.2-1).

Total Nitrogen

Total nitrogen (TN) concentrations during Year 3 averaged 19.9 mg/L in the influent (range: 0.330 to 72.0 mg/L), 5.47 mg/L at the midpoint (range: 0.390 to 14.0 mg/L) and 2.94 mg/L in the effluent (range: 0.340 to 12.0 mg/L).

Seasonal trends were almost identical to nitrate, since NO_3-N was the dominant N species comprising, on average, 87.6%, 91.4% and 88.8% of TN in the influent, midpoint and effluent, respectively.

Statistical comparison of the changes in total nitrogen concentration between the sampling locations was carried out using the test known as Scheffe's Multiple Contrasts, which is particularly well suited for testing the significance of differences between concentrations (Zar 1974). The results for selected months are summarized in Table 4.5.6-1. The differences in N concentration between the influent and

TABLE 4.5.6-1

Statistical Comparison Of The Changes In The Total Nitrogen Concentrartions Occurring In The Upper And Lower Basins And In The Two Basins Combined At The Quinsam Wetland Project, January 1990 To March 1991. (a)

MONTH	BASIN 1 (upper)	BASIN 2 (lower)	BASINS 1+2 (combined)
JANUARY 1990	**	**	**
MARCH 1990	n.s.	**	**
APRIL 1990	**	n.s.	**
JUNE 1990	**	n.s	**
SEPTEMBER 1990	**	**	**
MARCH 1991	**	**	**

* = difference significant at a probability level of 0.05

** = difference significant at a probability level of 0.01

n.s. = difference not statistically significant

(a) Statistical comparison based on Scheffe's Multiple contrasts (Zar 1974).

effluent (i.e., as a result of the dosed water passing through the entire experimental wetland) was highly significant at all times of year. Non significant differences did occur, however, in each of the two wetland basins. In Basin 1 (i.e. influent versus midpoint), the change in total N concentration was highly significant throughout the year, except in March 1990, when concentration reduction was low as a result of the combined effects of exceptionally variable NO_3 loading (Figure 4.5.6-3) and low temperatures. This result contrasts with the highly significant difference in January 1990 when, while affected by similarly low temperatures, influent NO_3 concentrations were less variable. In Basin 2 (i.e. midpoint versus effluent), the change was usually highly significant except in April and June 1990, which represent the spring and summer growing season. During the warmer season of year, N removal was statistically significant only in the upper wetland basin; any further reduction in N concentration achieved by passage through the lower basin was not statistically significant. As might be expected because of the biologically mediated N removal processes, these results confirm that a much lower residence time is sufficient in spring and summer than at other times of year to effect significant N removal. As noted in Table 4.1.1-1, theoretical hydraulic retention times during the growing season ranged from 4.5 to 6.2 days in the two basin system. The effective HRT for significant N removal during the growing season would therefore be one half of this range, or approximately 2 to 3 days.

The changes in the fractions of NO_3, NO_2 and NH_3 in the total aqueous nitrogen passing through the wetland are indicative of the types of nitrogen transformations that were occurring in each basin of the experimental system. These changes in the constituents of TN are examined below.

The NO_3 percentages of TN given above suggest that the net reduction in NO_3 concentration in Basin 1 was less than the imports plus intra-basin nitrate formation (nitrification). Once the water had passed through the second basin, however, the removal processes had matched nitrification and the nitrate fraction of TN was again similar to levels in the influent. The predominant nitrate removal processes included denitrification, assimilation and dilution, acting in combination although at different relative rates.

It is highly likely that any increases in NO_3 concentration due to endogenous nitrification would have tended to occur during the summer and be counterbalanced by denitrification and NO_3 assimilation by vegetation and algae. Intra-basin nitrification is a microbially mediated process requiring oxygen. The natural diffusion rate of oxygen across the air-water interface is very slow (Mitsch and Gosselink 1986) and, consequently, the main O_2 source for nitrification would have been photosynthesis by aquatic plants (algae and macrophytes). Since plants are dormant during the winter, nitrification would only have occurred during the growing season, which is also the season of highest NO_3 uptake by plants. Moreover, nitrate is assimilated by plants preferentially over other forms of N.

The fraction of NH_3 was intermediate between nitrate and nitrite. The average ammoniacal fraction of TN increased through the wetland, from 0.92% in the influent, to 1.77% at the midpoint, and 3.16% in the effluent. Rather than originating from wastewater N inputs, the increases reflect production of ammonia in each basin, through mineralization of organic N in the wetland peat (see discussion of P concentrations in Section 4.5.7). Once released into solution, some of this ammonia could have been oxidized to NO_2 and NO_3.

The nitrite fraction of TN increased on average from 0.15% in the influent, to 0.31% at the midpoint, and 0.68% in the effluent. This increase reflects the net production of NO_2 in each basin (that is, the NO_2 removal rate was lower than the rate of addition and intra-basin production through, for example, oxidation of ammonia). Given the predominance of NO_3 and the marked reductions in NO_3 concentrations, the increase in NO_2 can be attributed to the partial denitrification involving the reduction of nitrate to nitrite. A secondary source of NO_2 may have been the oxidation of endogenous ammonia.

Section 4.6 provides further discussion of nitrogen production and removal processes in the wetland by means of a mass balance analysis.

4.5.7 Phosphorus

Concentrations of phosphorus (P) species are reported as mg/L of elemental P, to facilitate the mass balance computations presented in Section 4.6. Phosphorus data summary tables are included in Appendix B-1.

Orthophosphate

Orthophosphate P (PO_4) concentrations at all sampling points were usually below the 0.002 mg/L detection limit. The highest levels measured were 0.005 mg/L and 0.003 mg/L in one sample replicate each of the influent and effluent, respectively, on January 23, 1990.

The yearly range of PO_4 concentrations during Year 3 was similar to Years 1 and 2 (Norecol 1989, 1990). The data for the entire study indicate that lowest concentrations occurred in spring, probably due to dilution by snowmelt, and the highest concentrations occur in association with the early fall rain storms, when accumulated PO_4 was flushed from the wetland.

Total Dissolved Phosphorus

Concentrations of total dissolved phosphorus (TDP) averaged 0.005 mg/L in the influent (range: <0.002 to 0.043 mg/L), 0.005 mg/L at the midpoint (range: <0.002 to 0.061 mg/L) and 0.008 mg/L in the effluent (range: <0.002 to 0.125 mg/L). Variability within sampling sites was high, with C.V. values of 68%, 101% and 95%, respectively.

Figure 4.5.7-1 shows the changes in TDP concentrations between November 20, 1989 and March 31, 1991. Throughout most of the monitoring period, TDP concentrations were usually below 0.05 mg/L, except from late May to early July 1990, when higher values were measured, especially in the effluent.

During November 1989 through mid January 1990, and again in February 1991, influent TDP tended to be higher than at the midpoint or effluent, possibly reflecting high background P content from winter runoff entering the mine settling pond. Influent TDP also increased sporadically in late spring and early summer (May 22 through July 3, 1990), though levels were usually lower than in the midpoint and effluent samples (Figure 4.5.7-1). These increases coincide with periods of frequent rainfall and increasing temperatures and therefore probably reflect a combination of higher P loading to the settling pond and increasing dissolution of P from mineral and organic matter in the pond and its catchment area.

Midpoint TDP concentrations were usually lower than in the effluent. The highest midpoint TDP concentrations occurred in mid June (0.017 mg/L) and early July (0.028 mg/L) in association with high rainfall events (Figure 4.1.2-1). Peak TDP concentrations in the effluent occurred on the same dates, and were higher than at the midpoint (0.019 mg/L and 0.060 mg/L, respectively).

A steady increase in TDP concentration occurred during the mid summer drought in the influent, and likely reflects evaporative concentration of TDP in the settling pond. Peak TDP values measured in the wetland, especially at the outlet, during the latter half of the drought are indicative of high evapo-transpiration rates in the wetland.

The seasonal trends in TDP concentration during Year 3 were similar to Year 2 and Year 1 (Norecol 1990, 1989).

Total Phosphorus

Total phosphorus (TP) concentrations during Year 3 averaged 0.009 mg/L in the influent (range: <0.002 to 0.046 mg/L), 0.007 mg/L at the midpoint (range: <0.002 to 0.035 mg/L) and 0.009 mg/L in the effluent (range: <0.002 to 0.125 mg/L). Variability at each sampling site was high, with C.V. values of 85%, 84%, and 46%, respectively.

TOTAL DISSOLVED PHOSPORUS CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

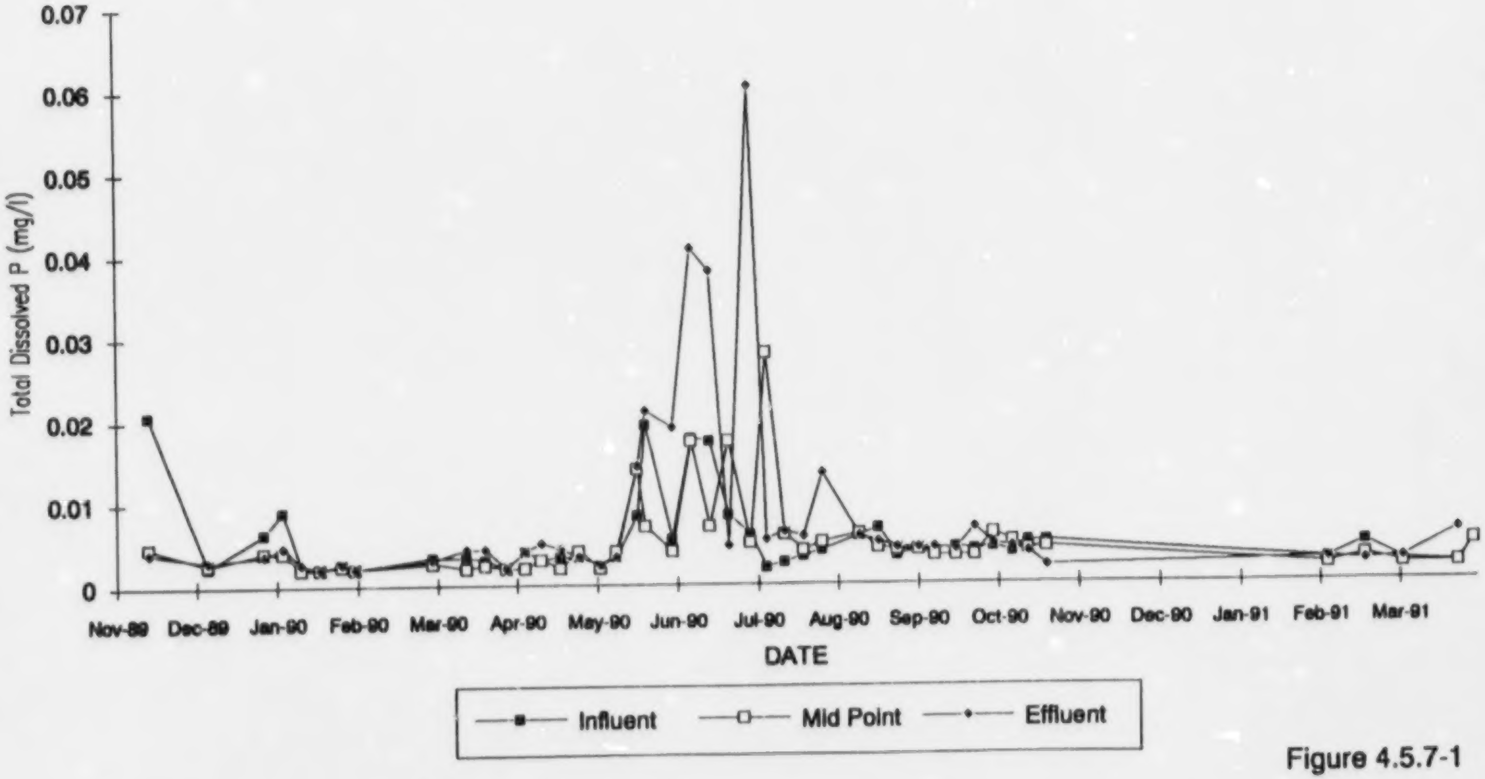


Figure 4.5.7-1

The TDP fraction of total P increased on average through the wetland, from 56% in the influent, to 71% at the midpoint and 89% in the effluent. Particulate P (defined as TP minus TDP) was therefore highest in the influent and tended to decrease as the water passed through the wetland. As during Year 2, the data suggest that particulate P exports from the wetland occurred mainly in spring due to fragmentation of vegetation.

The ortho-P fraction of TP was usually low, since ortho-P in most samples was below the detection limit of 0.002 mg/L. The highest measurable fraction in the influent was 27% of TP in late January 1990. On this same date, the ortho-P fraction in the midpoint and effluent samples was 33% and 75%, respectively, of 0.006 and 0.004 mg/L of TP. The limited data suggest that ortho-P was being generated within the wetland through decomposition processes, although at very low levels, near the 0.002 mg/L detection limit.

Seasonal changes in P flux are discussed in Section 4.6.2.

4.5.8 Metals

The metals concentrations observed are considered to represent primarily natural background conditions with little or no influence due to mining activities. An overview of the general trends for dissolved and particulate fractions of Al, Cu, Fe, K, Mn, and Zn is provided in Appendix B-1. The particulate fraction was defined as the total concentration minus the dissolved concentration. Data summary tables and graphs are also provided in Appendix B-1. More detailed statistical analysis of metals concentrations, while possible with the data obtained, was beyond the scope of the study.

4.6 Nutrient Mass Removal

4.6.1 Nitrogen

Table 4.6.1-1 summarizes the mass balance of nitrogen and phosphorus obtained in the experimental wetland between November 1989 and March 1991. Of the approximately 89 kg of N added to the wetland via the dosed influent, 87.4 kg were removed, representing an overall mass removal efficiency of 98.2%. Based on the average N content of above-ground vegetation (Section 4.4.1), the above-ground portion of vegetation biomass accounted for an estimated 7.1 kg or 8.0% of the N inputs. Based on the hydrological estimates and groundwater N concentration data (Section 4.3.5), N losses due to exfiltration accounted for an estimated 5.2 kg or 5.8% of the N inputs. The remaining N removal occurred via a combination of other known pathways, namely, denitrification, assimilation into below-ground biomass (including roots, rhizomes and soil micro-organisms), and production of herbivorous macrofauna. These pathways combined accounted for 75.4 kg or 84% of the N inputs.

TABLE 4.6.1-1

NITROGEN AND PHOSPHORUS MASS BALANCE
IN THE EXPERIMENTAL WETLAND
NOVEMBER 1989 TO MARCH 1991

DESCRIPTION	UNITS	NITROGEN	PHOSPHORUS
Total mass added via influent	(g)	89021	42.263
Mass removed via plant growth (above-ground)	(g)	7120	0.688
	(% of input)	8.0%	1.6%
	(% of removal)	8.1%	5.5%
Mass removed via exfiltration	(g)	5158	0.127
	(% of input)	5.8%	0.3%
	(% of output)	5.9%	1.0%
Mass removed via below-ground biota, & microbial pathways	(g)	75159	11.644
	(% of input)	84.4%	27.6%
	(% of output)	86.0%	93.5%
Total mass removed	(g)	87437	12.459
	(% of input)	98.2%	29.5%
Mass exported via effluent	(g)	1584	29.804
	(% of input)	2%	71%

The highest proportion of the total N mass removed occurred via the combined pathways of denitrification and production of below-ground biomass and macrofauna. Of these, production of macrofauna is probably the least significant, although its contribution to N removal was not quantified. Production of above-ground plant tissue accounted for 8.1%, while exfiltration accounted for 5.9% of the remaining N mass removal. If it is assumed for discussion purposes that the below ground vegetation fraction represents at most twice the above-ground fraction (published range is 10 to 70% of total biomass (Mitsch and Gosselink 1986)), then it is evident that denitrification is the major N removal pathway, accounting for at least 77% of the mass removed.

Seasonal changes in N mass removal efficiency during Year 3 are summarized by month in Figure 4.6.1-1. Areal N mass removals are summarized in Table 4.6.1-2. Total N removal efficiencies were always above 80%, even in winter (periods of complete freeze-up excluded), and maximum efficiencies, approaching 100%, occurred during summer. The lower efficiency in June 1990 (68% for NO_3) reflects the lower N loading rate that occurred due to interruptions in NO_3 dosing. Export of NH_3 and NO_2, indicated by negative mass removal values occurred during winter only.

A comparison of N mass removal efficiencies measured during the three yearly monitoring periods of the study is shown in Table 4.6.1-3. Mass removal efficiency increased over the three year period, by 9% between Years 1 and 2, and by 2% between Years 2 and 3. The apparent differences between years may be due to the different durations of the monitoring periods covered. Considering the high removal efficiency obtained during Year 3, it is evident that the wetland functioned very effectively as a nitrogen removal system. Figure 4.6.1-2 summarizes the NO_3-N mass removal efficiencies obtained over the three years of the study. Peak removal efficiencies near 100% occurred consistently during summer. The lowest efficiency always occurred in winter (when receiving water sensitivity is lowest) and appeared to decline from one year to the next. A multi-year monitoring program would be necessary to determine if the declining winter efficiencies represent a trend or are merely an artifact of natural variability.

4.6.2 Phosphorus

The P mass balance is shown in Table 4.6.1-1. Total phosphorus inputs to the experimental wetland via the influent were estimated at 42.3 g, at a ratio of about 1:2100 with N inputs. Overall P mass removal efficiency was 29.5%, considerably lower than that of N. Of the P input, approximately 0.69 g (1.6%) was removed via plant leaves and stems and 0.13 g (0.3%) via exfiltration losses. The major portion of P removal (11.6 g or 27.6% of inputs) occurred via below ground pathways, including assimilation and storage in plant roots and rhizomes, and in soil micro-organisms, and possibly via immobilization by adsorption or complexation in

SEASONAL TOTAL NITROGEN REMOVAL EFFICIENCY OF THE EXPERIMENTAL WETLAND , DECEMBER
1989 TO MARCH 1991

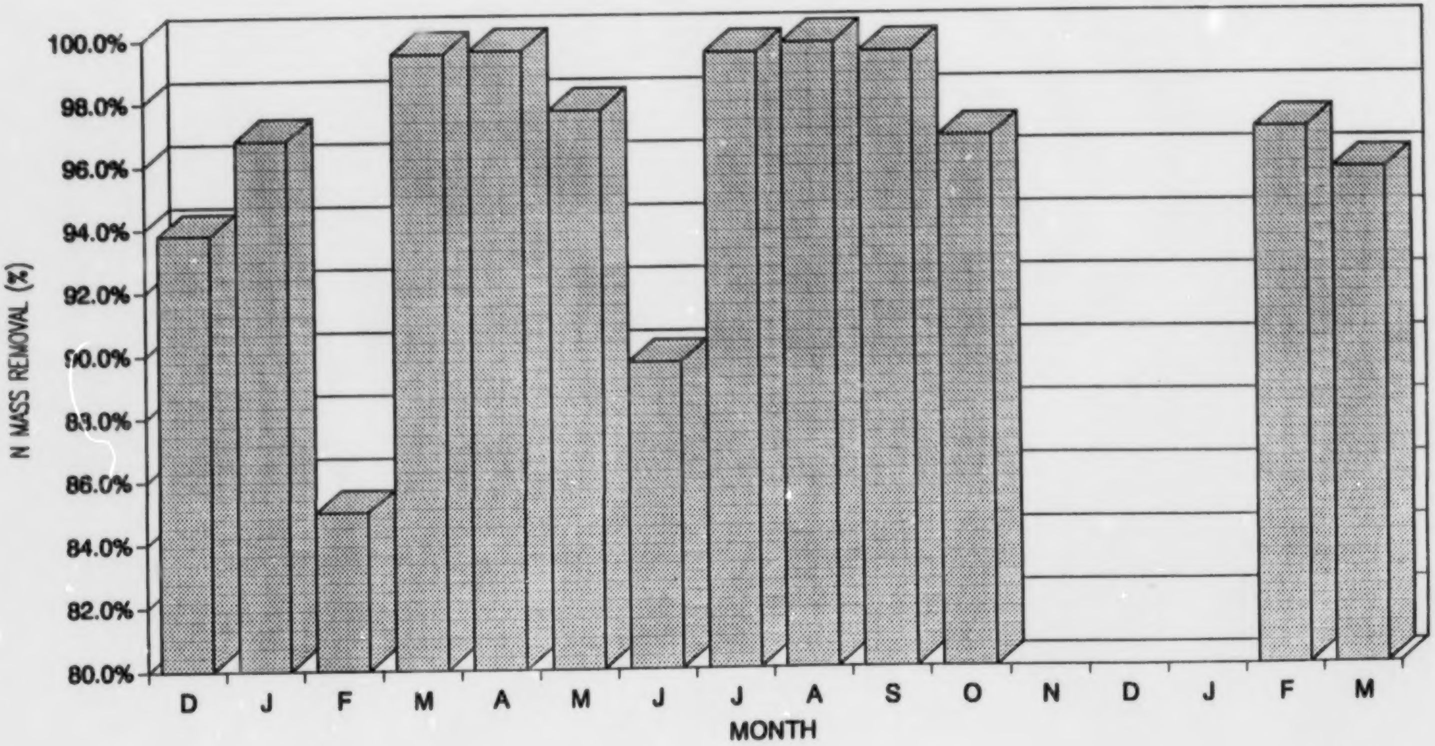


Figure 4.6.1-1

TABLE 4.6.1-2

MONTHLY AVERAGE MASS AND PERCENT REMOVALS OF TOTAL, NITRATE, AMMONIA AND NITRITE NITROGEN AT THE EXPERIMENTAL WETLAND AT QUINSAM COAL MINE BETWEEN DECEMBER 1989 AND MARCH 1991

MONTH	TOTAL-N		NO_3-N		NH_3-N		NO_2-N	
	kg/ha/d	%	kg/ha/d	%	kg/ha/d	%	kg/ha/d	%
December	2.330	93.8	3.930	89.4	-0.004[a]	-35.0	-0.003	-54.3
January	3.165	96.8	1.787	76.9	-0.014	-338.7	-0.001	-288.0
February	1.526	85.0	3.065	84.7	-0.0004	-11.7	-0.001	-135.0
March	2.862	99.5	1.453	97.1	0.017	34.7	0.002	50.7
April	3.540	99.6	3.590	99.5	0.004	35.5	0.006	86.2
May	2.697	97.7	3.854	95.3	0.002	26.5	0.0003	94.8
June	1.080	89.7	0.890	67.6	0.002	34.4	0.005	62.1
July	2.251	99.5	1.508	100.0	0.040	97.0	0.006	96.4
August	2.819	99.8	2.514	100.0	0.051	96.0	0.001	84.6
September	2.762	99.5	1.970	98.4	0.008	41.2	-0.003	-458.0
October	5.913	96.8	5.305	78.4	0.071	91.9	0.010	74.4
November	-[b]	-	-	-	-	-	-	-
December	-	-	-	-	-	-	-	-
January	-	-	-	-	-	-	-	-
February	2.897	97.0	2.076	80.0	0.054	63.5	0.003	14.8
March	3.701	95.7	2.819	72.4	0.034	74.2	-0.007	-216.0

[a] Negative values indicate mass export from the wetland.

[b] Monitoring interrupted due to funding cut.

TABLE 4.6.1-3

COMPARISON OF NITROGEN AND PHOSPHORUS MASS REMOVAL EFFICIENCY AMONG THE THREE YEARS OF THE WETLAND STUDY AT QUINSAM MINE

AUGUST 1988 TO MARCH 1991

PARAMETER		YEAR 1	YEAR 2	YEAR 3
Nitrogen				
Inputs	g	17584	42275	89021
Outputs	g	2291	1539	1584
Removal Efficiency	%	87	96	98
Phosphorus				
Inputs	g	52.8	9.0	42.3
Outputs	g	31.8	4.7	29.8
Removal Efficiency	%	40	48	30

SEASONAL NITRATE-N MASS REMOVAL EFFICIENCY OF THE QUINSAM EXPERIMENTAL WETLAND,
AUGUST 1988 TO MARCH 1991

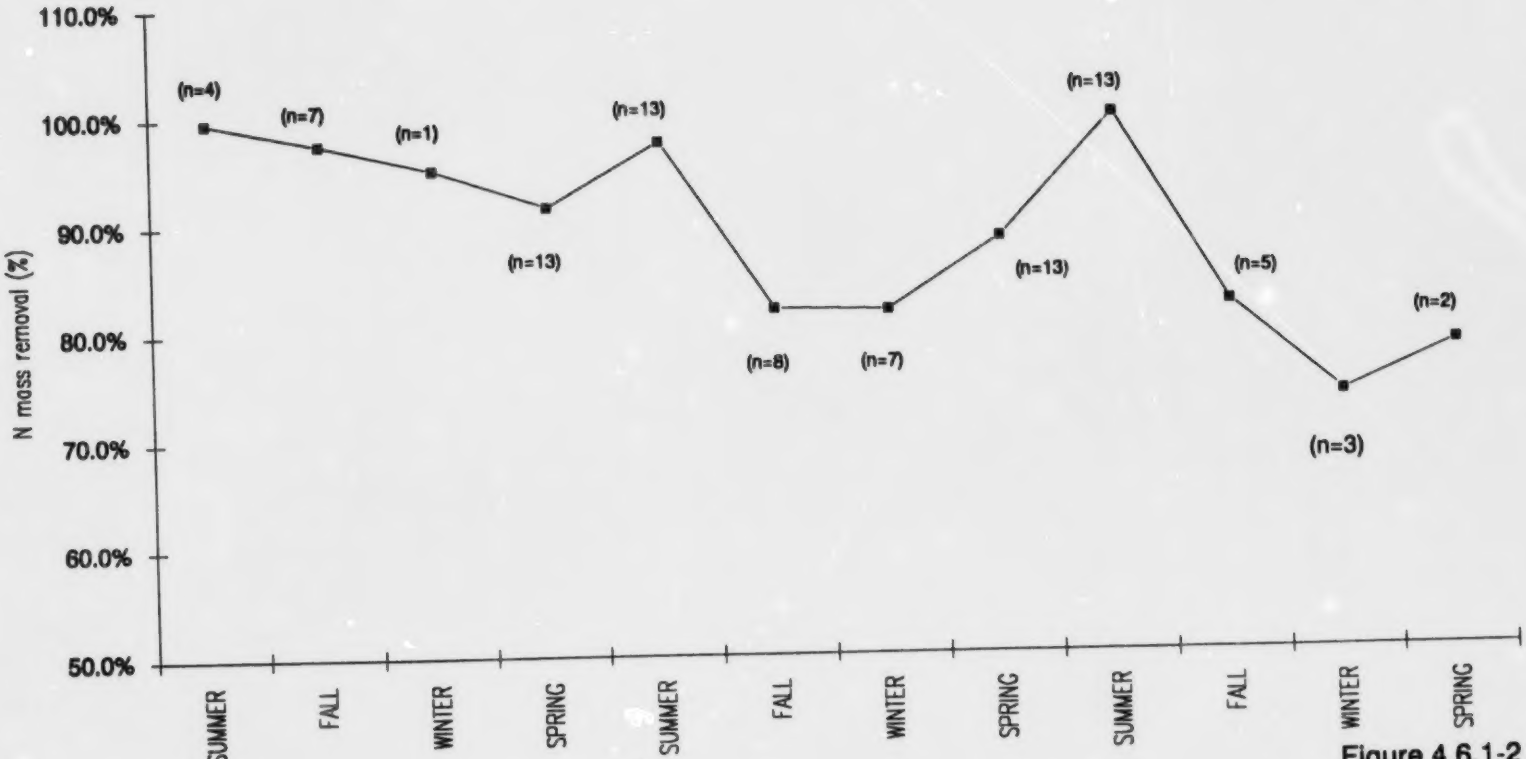


Figure 4.6.1-2

the wetland peat. Above-ground vegetation and exfiltration accounted for approximately 5.5% and 1% respectively, of the total P removed. Below-ground pathways accounted for 93.5% of P removal.

The apportionment of P removal via the below-ground pathways described above can be estimated crudely, as with N, by assuming that the P in root and rhizome biomass represents up to 2 times the above-ground biomass P or approximately 11% of total P outputs. Based on this assumption, the estimated fraction of P removal attributable to microbial and physico-chemical pathways in the soil is 83%.

Seasonal P removal efficiencies during Year 3 are compared by month in Figure 4.6.2-1. Areal mass removals are summarized in Table 4.6.2-1. Phosphorus removal efficiencies were lower than for N and much more variable. Negative values in April 1990 and March 1991 indicate net export of P caused by flushing of particulate matter from the wetland during heavy rains. Export of P in June 1990 appears to have been due to release of dissolved P. Efficiencies were high, however, during the summer, when levels between 40 and 50% P removal occurred. The reason for high P removal (>50%) in December 1989 is unclear, but is more likely to have been physical-chemical rather than biological in nature. It is worth noting that P exports were not a concern with respect to downstream water quality, due to the low concentrations involved (Section 4.5.7).

A comparison of P removal efficiencies during each of the three years of the study is shown in Table 4.6.1-1. Phosphorus mass removal increased by 8% from 40 to 48% between Years 1 and 2, and then decreased by 18% in Year 3. It is known that P must accumulate in a wetland since there is no export mechanism corresponding to denitrification and, unless the P contained in biomass or soil is physically removed from the system, saturation will eventually occur. The higher P removal measured during Years 1 and 2 may reflect the effects of low saturation in a recently constructed wetland system, where removal by incorpation into recovering vegetation and a developing soil microbiota is high. The decrease in P removal efficiency during Year 3 suggests that the wetland plant community in the constructed system had stabilized and P export via decomposition of recently produced leaf biomass and accelerated decomposition of pre-disturbance surface peat layers had increased.

SEASONAL TOTAL PHOSPHORUS REMOVAL EFFICIENCY OF THE EXPERIMENTAL WETLAND, DECEMBER 1989 TO MARCH 1991

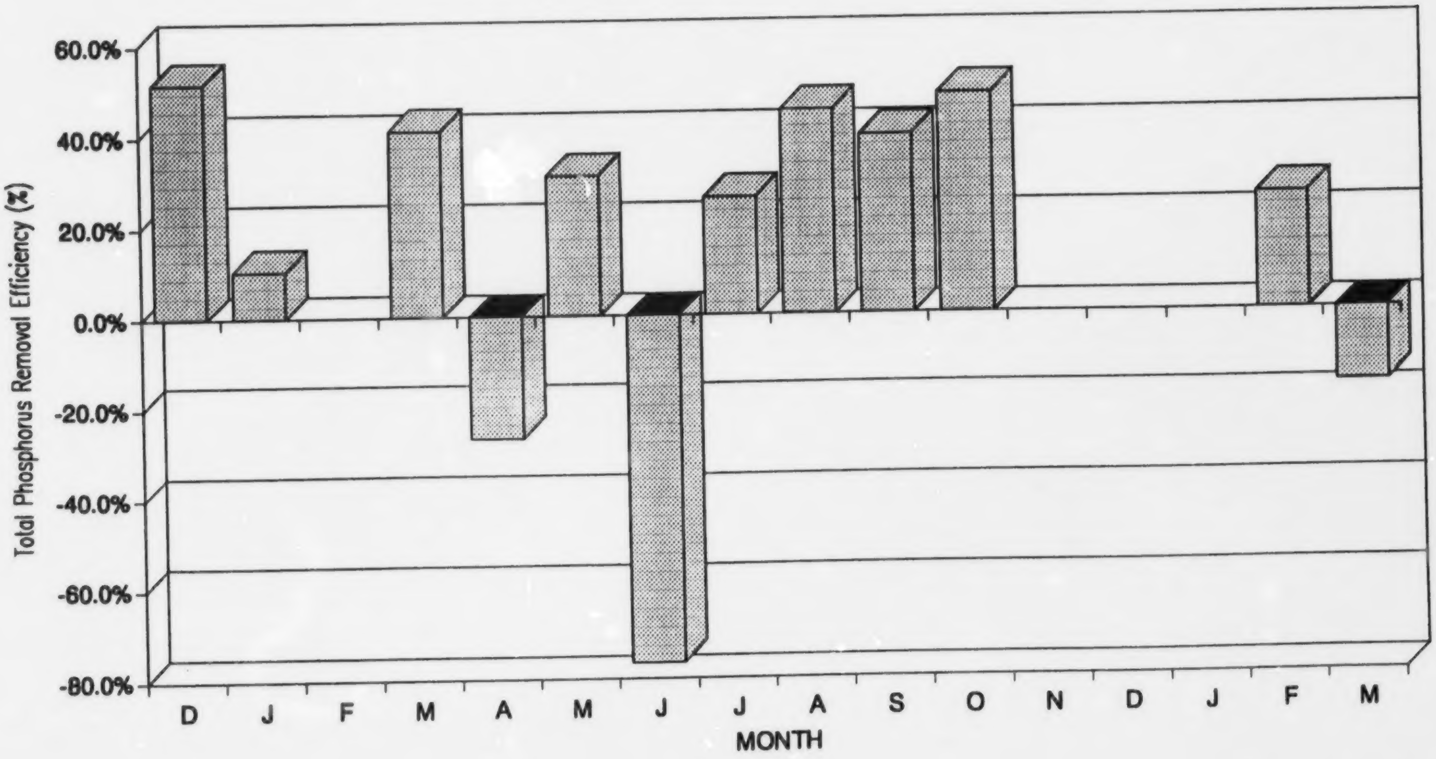


Figure 4.6.2-1

TABLE 4.6.2-1

MONTHLY AVERAGE MASS AND PERCENT REMOVALS OF TOTAL, DISSOLVED, AND PARTICULATE PHOSPHORUS IN THE EXPERIMENTAL WETLAND AT QUINSAM COAL MINE BETWEEN DECEMBER 1989 AND MARCH 1991

MONTH	TOTAL-P		DISSOLVED P		PARTICULATE P	
	g/ha/d	%	g/ha/d	%	g/ha/d	%
December	0.314	51.6	0.019	6.7	0.295	90.9
January	0.824	10.4	0.234	34.0	0.886	64.3
February	0.512	56.9	0.037	17.0	0.475	69.4
March	0.723	41.1	0.399	51.7	0.323	23.4
April	-0.206[a]	-26.9	0.209	30.1	-0.415	-377.0
May	0.397	30.9	0.525	42.4	0	0
June	-0.782	-76.6	-3.071	-133.0	0	0
July	0.250	26.0	-0.763	-329.0	0.134	56.0
August	1.135	45.0	0.605	50.8	0.681	12.1
September	0.586	39.4	0.294	36.4	0.292	43.1
October	0.990	48.4	0.364	33.3	0.626	61.5
November	-[b]	-	-	-	-	-
December	-	-	-	-	-	-
January	-	-	-	-	-	-
February	0.548	25.6	0.188	32.9	0.266	22.8
March	-0.164	-16.2	-0.033	-6.3	-0.109	-28.4

[a] Negative values indicate mass export from the wetland.
[b] Monitoring interrupted due to funding cut.

PRELIMINARY WETLAND DESIGN CRITERIA

5.1 Background

Wetland design criteria and performance expectations with respect to nitrate removal are examined in this section, in light of the results obtained during the present study. Other nitrogen species, such as ammonia and nitrite, are not addressed since nitrate was the predominant N form in the mine drainage being simulated. While ammonia and nitrite were at times exported from the experimental wetland in small amounts, at no time did these concentrations reach levels which are considered to be an environmental hazard.

The approach taken here is primarily empirical. That is, it assumes that by approximating the conditions of the pilot wetland at Quinsam, other mines can achieve a satisfactory (>80%) nitrate removal. The data included in this and earlier reports (Norecol 1989, 1990) used in combination with data which will be generated by future studies should contribute to the development of quantitative design criteria based on kinetics.

Since both the nitrate concentrations and drainage flows at a mine site are quite variable, the design should be based primarily on mass loading and hydraulics. Also, the design should be based on the mass loadings expected during the growing season, between early spring and early fall, since this is the period during which the receiving environment will be most sensitive to additional nutrient inputs. While high mass exports can occur during other times of the year, the ability to control nutrients with wetland systems outside the growing season is more limited. Moreover, the potential downstream impacts are generally less, due to both the lower biological response during fall and winter and the greater dilution with increasing distance from the discharge point.

5.2 Performance Expectations

The results obtained at Quinsam (April to October) in Years 2 and 3 indicate that a natural wetland containing at least 60 cm of peat and a growing macrophyte vegetation community can achieve nitrate mass removals of 0.9 to 14.8 kgN/ha/d during the growing season. These mass removal rates were achieved when average influent NO_3-N concentrations ranged between 10 and 120 mg/L and hydraulic retention times ranged between 4 and 8 days (2 and 4 days in each of the two basins). It should be noted that nitrate concentrations in drainage from operating mines which are recognized as having a nitrate release problem usually do not exceed 20 mg/L (Ferguson and Leask 1988). Resulting effluent NO_3 concentrations ranged between

<0.002 and 32 mg/L at the briefer retention times (one basin only) and between <0.002 and 11 mg/L at the longer retention times (two basins). The highest mass loading rates coincided with the highest mass removal rates. Peak effluent NO_3 concentrations, occasionally higher than the 10 mg/L guideline for protection of potable water supply, occurred in the experimental systems during the very high loading rates which would occur rarely or not at all in natural circumstances at an operating mine.

5.3 Design Criteria

The following design criteria are provided, based on the performance of the Quinsam pilot project, to achieve high N removal efficiency (up to 10 kgNO_3-N/ha/d) in a natural wetland receiving nitrate-rich mine drainage

- Provide up-stream sedimentation and, to the extent possible, flow equalization;
- Maximum water depth: 0.10 m
- Minimum hydraulic retention: 3 days (theoretical value based on peak growing season flows)
- Channel length to width ratio: >5:1 (provided by baffles)
- Provide laminar flow by preventing or correcting micro-channelling, through use of baffles and/or by blocking existing small channels.

Site elevation will also affect system performance, since mean temperatures decrease at higher elevations and the growing season is shorter. Because metabolic activity decreases with decreasing ambient temperatures, it would be advisable to increase the hydraulic retention time with increasing altitude. Despite the longer daylight at higher latitudes, a similar approach of increasing the retention time is probably desirable.

5.4 Construction and Maintenance

The construction of an entirely new wetland where none has existed before should follow the same guidelines recommended above. Measures should be taken to minimize exfiltration, although an impermeable liner is probably only necessary if there is no suitable clay or till material available. Organic soil and wetland vegetation would have to be imported. It is essential that a substantial layer of organic soil or peat, at least 0.3 m but preferably 0.6 m, be provided to ensure the availability of a suitable microflora for denitrification and to provide a rooting medium for wetland vegetation. Careful attention should be given to grading the imported soil to provide a flat surface and encourage laminar flow within the wetland.

Wetland vegetation is best obtained from native stock in the vicinity, with sedges or similar emergent species being preferred over woody shrubs. Because of the potential of cattail to become a nuisance weed, cattail should be used only if it is already common to the general locality. Transplanting stock can be collected in the late fall or spring, although spring planting is probably best due to higher survival rates. Rhizome cuttings or root masses can be planted at a maximum spacing of 1 m, although closer spacing (e.g., 0.5 m centres) is desirable since it will give rise to earlier establishment of a dense vegetation cover. Seeds can also be collected from natural wetlands, preferably in late summer or early fall. Seed heads can be gathered with minimum damage to the donor site, preferably stored dry during winter, and sowed onto the prepared soil in the spring. Based on the experience at Quinsam with cattail transplants, a dense stand can become established within two growing seasons of transplanting. Harvesting is not necessary to optimize N removal.

CONCLUSIONS

6.1 Nitrogen Removal

Nitrogen removal in the experimental wetland between November 20, 1989 and March 31, 1991 (Year 3), represented approximately 98% of the N added via the influent. The overall mass removal rate for the 496-day monitoring period was 0.220 $g/m^2/d$. The nitrogen mass removal efficiency during Year 3 was comparable to the 96% obtained during Year 2 and higher than the 87% obtained during Year 1.

Influent nitrate-N concentrations of up to 47 mg/L during Year 3 were reduced to 0.001 to 12.6 mg/L after a theoretical retention time of 4.3 to 8.2 days in the wetland. Ammonia and nitrite were commonly exported from the wetland, although at very low concentrations which are not considered harmful to aquatic life. Average effluent concentrations were 0.093 mg/L total ammonia-N and 0.020 mg/L nitrite-N. The seasonal trends observed with respect to the N species were similar among the three years of the study.

Denitrification in the wetland soils accounted for an estimated 86% of N removal, followed by above-ground plant growth (8.1%) and exfiltration (5.9%).

The nitrogen removal results obtained in this study with a low-level nitrogen wastewater are considerably better than those commonly obtained with high-nitrogen wastewaters such as domestic sewage.

6.2 Phosphorus Removal

Phosphorus removal in the experimental wetland during Year 3 represented approximately 30% of the P added via the effluent. The average P removal rate for the 496 day period was 0.031 $mgP/m^2/d$. Export of particulate P occurred during rains in April 1990 and March 1991, and export of dissolved P occurred during decomposition of organic matter in June 1990. Maximum concentrations of (potentially bio-available) orthophosphate-P remained at or below the 0.002 mg/L detection limit during most of the period. The P concentrations and seasonal trends were similar among the three years of the study.

Mass removal via precipitation, physico-chemical immobilization in the wetland soils and assimilation by below-ground microbial/vegetation biomass accounted for 93.5% of P removal, followed by above-ground biomass production (5.5%) and exfiltration (1%).

6.3 Metals

6.3.1 Aluminum

Aluminum tended to be exported in dissolved form during the growing season as a result of vegetation decay. In contrast, dissolved Al tended to be removed during the fall and winter. Similar patterns were observed in Years 1 and 2.

6.3.2 Copper

Copper occurred primarily in dissolved form and both dissolved and particulate Cu tended to be removed in the wetland. This contrasts with the results obtained during Years 1 and 2, when particulate Cu concentrations tended to increase through the wetland during the growing season.

6.3.3 Iron

Iron occurred primarily as dissolved Fe and tended to be exported from the wetland during the growing season and removed during the remainder of the year. The seasonal trends were similar among the three years of the study.

6.3.4 Potassium

Potassium occurred primarily in dissolved form and was removed through the wetland during all three years of the study. Elevated K levels in the wetland were due to the use of KNO_3 to as the nitrate enrichment compound.

6.3.5 Manganese

Manganese occurred almost entirely in dissolved form and tended to be removed in the wetland. Mn was monitored only during Year 3.

6.3.6 Zinc

Zinc occurred almost entirely in dissolved form and tended to be removed in the wetland. Export of particulate Zn tended to occur during spring and fall rains. Seasonal trends were similar among the three years of the study.

6.4 Wetland Design Considerations

The study has confirmed empirical design guidelines adapted from wetlands treatment experiences with municipal sewage. The data generated during the three-year study can be used in combination with the results of other studies to develop preliminary kinetics-based design criteria for nitrate removal.

REFERENCES

Adriano, D. C., A. Fulenwider, R. R. Sharitz, T. G. Ciravolo and G. D. Hoyt. 1980. Growth and mineral nutrition of cattail (Typha) as influenced by thermal alteration. J. Environ. Qual., 9:649-653.

Auclair, A. N. D. 1979. Factors affecting tissue nutrient concentrations in a Scirpus - Equisetum wetland. Ecology, 60(2): 337-348.

Babcock, M. F., D. W. Evans and J. J. Alberts. 1983. Comparative uptake and translocation of trace elements from coal ash by Typha latifolia. The Science of the Total Environment, 28:203-214.

Barko, J. W. and R. M. Smart. 1978. The growth and biomass distribution of two emergent freshwater plants, Cyperus esculentus and Scirpus validus, on different sediments. Aquatic Botany, 5:109-117.

Bayly, I. L. and T. A. O'Neill. 1972. Seasonal ionic fluctuations in a Phragmites communis community. Can. J. Bot., 50:2103-2109.

Birkbeck, A.E., D. Reil and R. Hunter. 1990. Application of natural and engineered wetlands for treatment of low strength leachate. pp.411-418 in: Constructed Wetlands in Water Pollution Control. P.F. Cooper and B.C. Findlater (eds.). Pergamon Press, Oxford.

Boyd, C. E. and L. W. Hess. 1970. Factors influencing shoot production and mineral nutrient levels in Typha latifolia. Ecology, 51(2):296-300.

Brix, H. 1987. Treatment of wastewater in the rhizosphere of wetland plants - the root-zone method. Wat. Sci. Tech., Vol 19, Rio, pp.107-118.

Brodie, G.A., D.A. Hammer and D.A. Tomljanovich. 1988. Constructed wetlands for acid drainage control in the Tennessee Valley. in: Mine Drainage and Surface Mine Reclamation, Vol.1, Mine Water and Mine Waste. Bureau of Mines Information Circular 9183.

Cary, P. R. and P. G. C. Weerts. 1984. Growth and nutrient composition of Typha orientalis as affected by water temperature and nitrogen and phosphorus supply. Aquatic Botany, 19:105-118.

Cooper, P.F. and J.A. Hobson. 1987. State of knowledge on reed bed treatment systems. Water Research Processes. Water Research Centre Report.

Cooper, P.F. and J.A. Hobson. 1989. Sewage treatment by reed bed systems: the present situation in the United Kingdom. Section 11 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.153-172.

Davis, C. B. and A. G. van der Valk. 1978. The decomposition of standing and fallen litter of Typha glauca and Scirpus fluviatilis. Can. J. Bot. 56:662-675.

Dickerman, J. A. and R. G. Wetzel. 1985. Clonal growth in Typha latifolia: population dynamics and demography of the ramets. J. Ecology, 73:535-552.

Dickman, M., C. Prescott and K. L. E. Kaiser. 1983. Variations in the aquatic vegetation of the Wetland River (Ontario, Canada) above and below an industrial waste discharge. J. Great Lakes Res., 9(2):317-325.

Environmental Protection Agency (U.S.) 1979. Aquaculture Systems for Wastewater Treatment, Seminar Proceedings and Engineering Assessment. EPA 430/9-80-006: 485p.

Environmental Protection Agency (E.P.A.). 1975. Process Design Manual for Nitrogen Control. United States Environmental Protection Agency. Technology Transfer. Washington, D.C.

Ewing, K. 1983. Environmental controls in Pacific Northwest intertidal marsh plant communities. Can. J. Bot., 61:1105-1116.

Ferguson, K. 1986. Preliminary Evaluation of Wetland Treatment at Mt. Washington. Unpublished letter to L. Erickson, Waste Management Branch, B.C. Ministry of Environment, from Conservation and Protection, Environment Canada. 17 November 1986.

Ferguson, K. and S.M. Leask. 1988. The Export of Nutrients from Surface Coal Mines. Regional Program Report 87-12. Environmental Protection, Conservation and Protection, Pacific and Yukon Region, Environment Canada, West Vancouver, B.C. 127 p.

Filbin, G. J. and R. A. Hough. 1982. In situ photosynthesis and respiration in the littoral sedge, Scirpus acutus Muhl. J. Freshwater Ecol., 1(5):443-450.

Francko, D. A. and R. G. Wetzel. 1984. The physiological ecology of cyclic adenosine 3, 5-monophosphate (cAMP) in vascular aquatic plants. I. In situ dynamics and relationship to primary production in a hardwater lake. Aquatic Botany, 19:13-22.

Fulton, G. W., W. T. Barker, and A. Bjugstad. 1983. Rooted aquatic plant revegetation of strip mine impoundments in the northern Great Plains. In: Proc. Third Biennial Plains Aquatic Research Conference, M.D. Scott (ed.), pp. 113-117.

Gallinger, R., L. Gormely, R. Kistritz and A. Sobolewski. 1991. Constructed Wetland Experiment for Treating AMD at Bell Copper. In: Reclamation and Sustainable Development. Proc. 15th Ann. Brit. Columbia Mine Reclamation Symp. and 16th Ann. Canadian Land Reclamation Meeting, June 24 - 28, 1991, Kamloops, B.C.

Girts, M.A. and R.L. Knight. 1989. Operations optimization. Section 34 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.417-430.

Girts, M.A. and R.L.P Kleinmann. 1983. Constructed wetlands for treatment of acid mine drainage: a preliminary review. Cited in: Watson et al. 1989, *op. cit.*

Grace, J. B. and R. G. Wetzel. 1982. Niche differentiation between two rhizomatous plant species: Typha latifolia and Typha angustifolia. Can. J. Bot., 60:46-57.

Grainger, J.M. (undated). An Overview of Sewage Treatment in Yukon Communities. Unpublished Report. Municipal Engineering Branch, Department of Community and Transportation Services, Government of Yukon, Whitehorse.

Guthrie, R. K. and D. S. Cherry. 1979. Uptake of chemical elements from coal ash and settling basin effluent by primary producers. I. Relative concentrations in predominant plants. The Science of the Total Environment, 12:217-222.

Haberl, R. and R. Perfler. 1989. Root-zone system: Mannersdorf - New Results. Section 39f in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.606-621.

Hammer, D.A. 1992. Creating Freshwater Wetlands. Lewis Publishers, Inc., 121 South Main Street, Chelsea, Michigan 48118. 298p.

Herskowitz, J. 1986. Town of Listowel Artificial Marsh Project Final Report, Project No. 128RR. in: Watson et al. 1989. *op.cit.*

Ho, S. 1979. Growth, chlorophyll and mineral nutrient studies on Phalaris arundinaceae L. in three Scottish lochs. Hydrobiologia, 63(1):33-43.

Hocking, P. J. 1981. Response of Typha domingensis to salinity and high levels of manganese in the rooting medium. Aust. J. Mar. Freshwater Res., 32:907-919.

Hocking, P. J. 1985. Effects of sodium and potassium chlorides on the growth and accumulation of mineral ions by Cyperus involucratus Rottb. Aquatic Botany, 21:201-217.

Hopkinson, C. S., J. G. Gosselink and R. T. Parrondo. 1978. Aboveground production of seven marsh plant species in coastal Louisiana. Ecology, 59(4):760-769.

Hutchinson, G. E. 1975. A Treatise on Limnology, Vol. III - Limnological Botany. John Wiley and Sons, New York. 660 p.

Jacobsen, B.N. 1985. Physical description of the root-zone installation at Ringsted and Rodekro municipalities, esperimental plan and preliminary results. in: Watson et al. 1989. *op.cit.*

Kadlec, R.H. 1987. Northern natural wetland water treatment systems. pp. 83-98 in: Aquatic Plants for Wastewater Treatment and Resource Recovery. K.R. Reddy and W.H. Smith (Eds.). Proceedings of the conference on Research and and Applications of Aquatic Plants for Water Treatment and Resource Recovery, July 20-24, 1986, Orlando, Florida. 1032 p.

Kadlec, R.H. 1989. Hydrologic factors in wetland water treatment. Section 3 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.21-40.

Kleinmann, R.L.P. and M.A. Girts. 1987. Acid mine water treatment wetlands: An overview of an emergent technology. pp.255-261 in: Aquatic Plants for Water Treatment and Resource Recovery. K.R. Reddy and W. H. Smith (eds.). Magnolia Publishing, Orlando, Florida.

Klohn Leonoff Inc. 1989. New Technology. Profile, August 1989.

Lakshman, G. 1983. A demonstration project at Humbold to provide tertiary treatment to the municipal effluent using aquatic plants. SRC Technical Report No. 151, Publication E-904-1-B-83, Saskatchewan Research Council.

Lakshman, G. 1984. A study to evaluate the potential of cattail as an energy crop. SRC Technical Report No. 162, Publication E-901-28-B-84, Saskatchewan Research Council.

Litchfield, D.K. and D.D. Schatz. 1989. Constructed wetlands for wastewater treatment at Amoco Oil Company's Mandan, North Dakota refinery. Section 18 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.233-238.

Liu, E. H., R. R. Sharitz and M. H. Smith. 1978. Thermal sensitivities of malate dehydrogenase enzymes in Typha. Amer. J. Bot., 65(2):214-220.

McNaughton, S. J., T. C. Folsom, T.Lee, F. Park, C. Price, D. Roeder, J. Schmitz and C. Stockwell. 1974. Heavy metal tolerance in Typha latifolia without the evolution of tolerant races. Ecology, 55:1163-1165.

Meiorin, E.C. 1989. Urban runoff treatment in a fresh/brackish water marsh in Fremont, California. Section 40b in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.677-685.

Merezhko, A. I., T. I. Shokod'ko, N. N. Smirnova and M. B. Dontsov. 1978. The reaction of Phragmites communis roots to DDT and Hexachlorane. Hydrobiol. J., 14(4):100. (abstract only)

Metcalf and Eddy, Inc. 1979. Wastewater Engineering: Collection, Treatment, Disposal, Reuse. McGrawHill Book Company, Inc. New York.

Mickle, A. M. and R. G. Wetzel. 1978a. Effectiveness of submersed angiosperm-epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. II. Dissolved organic carbon. Aquatic Botany, 4:317-329.

Mickle, A. M. and R. G. Wetzel. 1978b. Effectiveness of submersed angiosperm-epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. I. Inorganic nutrients. Aquatic Botany, 4:303-316.

Mickle, A. M. and R. G. Wetzel. 1979. Effectiveness of submersed angiosperm-epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. III. Refractory organic carbon. Aquatic Botany, 6:339-355.

Miller, G. 1989. Use of artificial cattail marshes to treat sewage in northern Ontario, Canada. Section 39i in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.636-642.

Mitsch, W.J., and J.G. Gosselink. 1986. Wetlands. Yan Nostrand Reinhold Co., New York. 539 p.

Morton, J. F. 1975. Cattails (Typha spp.) - Weed problem or potential crop? Economic Botany, 29:7-29.

Mudroch A. and J. A. Capobianco. 1979. Effect of mine effluent on uptake of Co, Ni, Cu, As, Zn, Cd, Cr, and Pb by aquatic macrophytes. Hydrobiologia, 64(3):223-231.

Muenscher, W. C. 1972. Aquatic Plants of the United States. Cornell University Press, Ithaca, NY,

Nordin, R.N. 1982. The effect on water quality of explosives use in surface mining. Volume 2: Effects on algal growth. Unpublished Ms. British Columbia Ministry of Environment.

Norecol Environmental Consultants Ltd. 1986. Potential Coal Mine Wastewater Treatment Options. Report prepared for the Environmental Protection Service, Mining, Mineral and Metallurgical Process Division.

Norecol Environmental Consultants Ltd. (Norecol). 1987a. Potential Coal Mine Wastewater Treatment Options. Manuscript Report MS 87-03. Conservation and Protection, Environmental Protection, Environment Canada.

Norecol Environmental Consultants Ltd. (Norecol). 1987b. Potential Coal Mine Wastewater Treatment Options II: Emergent Aquatic Plants. Manuscript Report MS 87-05. Conservation and Protection, Environmental Protection, Environment Canada.

Norecol Environmental Consultants Ltd. 1989. Evaluation of Wetlands for Nutrient Removal from Coal Mine Wastewater: Pilot Scale. Annual Report - Year 1. Report prepared for Mining and Metallurgical Process Division, Environmental Protection, Conversation and Protection, Environment Canada.

Norecol Environmental Consultants Ltd. 1990. Evaluation of Wetlands for Nutrient Removal from Coal Mine Wastewater: Pilot Scale. Annual Report - Year 2. Report prepared for Mining and Metallurgical Process Division, Environmental Protection, Conversation and Protection, Environment Canada.

Ondok, J. P. 1973. Photosynthetically active radiation in a stand of Phragmites communis Trin. Photosynthetica, 7(1): 8-17.

Pommen, L.W. 1983. The effect on water quality of explosives use in surface mining. Volume 1: Nitrogen sources, water quality and prediction, and management of impacts. British Columbia Ministry of Environment Technical Report 4., Victoria.

Reed, S.C. (Ed.) 1990. Natural Systems for Wastewater Treatment. Manual of Practice FD-16. Water Pollution Control Federation, 601 Wythe Street, Alexandria, Virginia, 22314-1994.

Reed, S.C. 1989. Wetlands as effluent treatment systems. in: Appropriate Wastewater Management Technologies for Rural Areas Under Adverse Conditions. D.H. Waller and A.R. Townshend, Eds.????

Reed, S.C., F.J. Middlebrooks, and R.W. Crites. 1988. Natural Systems for Waste Management and Treatment. McGraw-Hill Book Company, Inc. New York.

Ruttner, F. 1963. Fundamentals of Limnology (Third Edition). Translated by D.G. Frey and F.E.J. Fry. University of Toronto Press, Toronto. 295 p.

Sale, P. J. M. and R. G. Wetzel. 1983. Growth and metabolism of Typha species in relation to cutting treatments. Aquatic Botany, 15:321-334.

Sather, J.H. 1989. Ancillary benefits of wetlands constructed primarily for wastewater treatment. Section 28a in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.353-358.

Schierup, H. H. and V. G. Larsen. 1981. Macrophyte cycling of zinc, copper, lead and cadmium in the littoral zone of a polluted and a non-polluted lake. I. Availability, uptake and translocation of heavy metals in Phragmites australis (Cav.) Trin. Aquatic Botany, 11:197-210.

Sculthorpe, C. D. 1967. The Biology of Vascular Aquatic Plants. Edward Arnold Publishers Ltd. London. 610 p.

Sharitz, R. R., D. C. Adriano, J. E. Pinder III, J. C. Luvall and T. G. Ciravolo. 1984. Growth and mineral nutrition of cattails inhabiting a thermally-graded South Carolina reservoir. I. growth and the macronutrients. J. Plant Nutrition, 7(12):1671-1698.

Shokod'ko, T. I., A. I. Merezhko and A. I. Lyashenko. 1978. The effect of DDT and Hexachlorane on Assimilation and outflow of C in Phragmites communis. Hydrobiol. J., 23 (2):233-248.

Small, M.M. 1978. Wetlands, wastewater treatment systems. in: Watson et al. 1989. *op.cit.*

Snoddy, E.L., G.A. Brodie, D.A. Hammer and D.A. Tomljanovich. 1989. Control of the armyworm *Simyra henrici* (Lepidoptera: Noctuidae), on cattail plantings in acid drainage treatment wetlands at Widow's Creek Steam Electric Plant. Section 42i in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.808-811.

Spangler, F., W. Sloey and C. W. Fetter. 1976. Experimental use of emergent vegetation for the biological treatment of municipal wastewater in Wisconsin. In: Biological Control of Water Pollution, J. Tourbier and R.W. Pierson, Jr. (Eds.), University of Pensylvania Press. pp.161-172.

Staubitz, W.W., J.M. Surface, T.S. Steenhuis, J.H. Peverly, M.J. Lavine, N.C. Weeks, W.E. Sanford and R.J. Kopka. 1988. Potential use of constructed wetlands to treat landfill leachate. in: Hammer, D.A. 1989. *op.cit.*

Stephenson, M., G. Turner, P. Pope, J. Coet, A. Knight and G. Tchobanoglous. 1985. The Use and Potential of Aquatic Species for Wastewater Treatment. Appendix A. The Environmental Requirements of Aquatic Plants. Publication No. 65, California State Water Resources Control Board, Sacramento, California.

Stowell, R., R. Ludwig, J. Colt, and G. Tchobanoglous. 1980. Toward the rational design of aquatic treatment systems. cited in: Watson et al. 1988. *op. cit.*

Stowell, R. S. Weber, G. Tchobanoglous, B.A. Wilson and K.R. Townzen. 1985. Mosquito considerations in the design of wetland systems for the treatment of wastewaters. in: Ecological Considerations in Wetland Treatment of Municipal Wastewaters. P.J. Godfrey, E.R. Kaynor, S. Pelczarski, and J. Benforado, Eds. Van Nostrand Reinhold Company. pp.69-97.

Tamblyn, G. 1989. The Utilization of Wetlands as Tertiary Sewage Treatment Systems and Potential Environmental Impacts: A Preliminary Case Study of a New Hazelton Bog. Work Term Report. Department of Biology, University of Victoria, Victoria, B.C.

Taylor, G. J. and A. A. Crowder. 1983. Uptake and accumulation of heavy metals by Typha latifolia in wetlands of the Sudbury, Ontario region. Can. J. Bot., 61:63-73.

Taylor, T. M. C. 1983. The Sedge Family of British Columbia. Handbook No. 43, British Columbia Provincial Museum, Victoria. 375 p.

Thibodeau, F. R. and N. H. Nickerson. 1984. The effect of power utility right-of-way construction on cat-tail (Typha latifolia L.) marsh. Rhodora 86:389-391.

Thut, R.N. 1989. Utilization of artificial marshes for treatment of pulpmill effluents. Section 19 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.239-244.

Tourbier, J. and R. W. Pierson, Jr. (eds.) 1976. Biological Control of Water Pollution. University of Pennsylvania Press. 340p.

von Oertzen, I. and C. M. Finlayson. 1984. Wastewater treatment with aquatic plants: ecotypic differentiation of Typha domingenis seedlings. Environmental Pollution (Series A), 35:259-269.

Walrath, D. and A. S. Natter. 1976. Aquiculture - new broom cleans up wastewater. Water and Wastes Engineering, Feb. 1976. pp.38-41.

Warburton, D.B., W.B. Klimstra and J.R. Nawrot. 1985. Aquatic macrophyte propagation and planting practices for wetland establishment. pp.139-152. in: Wetands and Water Management on Mined Lands. Proceedings of a Conference, October 23-24, 1985, The Pennsylvania State University, Philadelphia. 393p.

Watson, J.T., F.D. Diodato, and M. Lauch. 1987. Design and performance of the artificial wetlands wastewater treatment plant at Iselin, Pennsylvania. in: Aquatic Plants for Wastewater Treatment and Resource Recovery, K.R. Reddy and W.H. Smith, Eds. Magnolia Publishing Inc., Orlando, Florida.

Watson, J.T., S.C Reed, R.H. Kadlec, R.L. Knight and A.E. Whitehouse. 1989. Performance expectations and loading rates for constructed wetlands. Section 27 in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.319-352.

Weldon, L. W., R. D. Backburn and D. S. Harrison. 1973. Common Aquatic Weeds. Dover Publications Inc., New York. 43 p.

Wolverton, B. C. 1982. Hybrid wastewater treatment system using anaerobic microorganisms and reed (Phragmites communis). Economic Botany, 36(4):373-380.

Wood, A. 1990. Constructed wetlands for wastewater treatment - engineering and design considerations. pp. 481-494 in: Constructed Wetlands in Water Pollution Control. P.F. Cooper and B.C. Findlater (eds.) Proceedings of the International Conference on the Use of Constructed Wetlands in Water Pollution Control, Cambridge, UK, 24-28 September 1990. International Association on Water Pollution Research and Control. Pergammon Press, Oxford. 605p.

Wood, A. and L.C. Hensman. 1989. Research to develop engineering guidelines for implementation of constructed wetlands for wastewater treatment in Soutern Africa. Section 39c in: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Edited by D.A. Hammer. "Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment, held in Chattanooga, Tennessee, June 13-17, 1988. Lewis Publishers Inc. 121 South Main Street, Chelsea, Michigan, 48118. pp.581-589.

Zar, J.H. 1974. Biostatistical Analysis. Prentice Hall, Inc. Englewood Cliffs, N.J. 620 p.

Appendix A

Summary of Kinetics-based Design Approaches for Surface and Sub-surface Flow Constructed Wetlands

Source: Watson, J.T., S.C. Reed, R.H. Kadlec, R.L. Knight and A.E. Whitehouse. 1988. Performance Expectations and Loading Rates for Constructed Wetlands. Ch. 27 in: Constucted Wetland for Wastewater Treatment: Municipal, Industrial and Agricultural. Donald A. Hammer, Ed. Lewis Pubishers, Inc., 121 S. Main Street, Chelsea, MI, 48118.

Constructed Wetlands with Surface Flow

The basic relationship for plug-flow reactors is given by Equation 1 for steady conditions:

$$\frac{C_e}{C_o} = \exp\left[-K_T t\right] \qquad (1)$$

where C_e = effluent concentration, mg/L
C_o = influent concentration, mg/L
K_T = temperature-dependent, first-order reaction rate constant, days^{-1}
t = hydraulic residence time, days

Reed et al.[46] suggest that experience with overland flow and trickling filter systems can be applied to constructed wetlands design. The resulting general model for BOD_5 is given in Equation 2:

$$\frac{C_e}{C_o} = A' \exp\left[\frac{-C' K_T (A_V)^{1.75}\, LWdn}{Q}\right] \qquad (2)$$

where A' = fraction of BOD_5 not removed as settleable solids near the head of the system (as a decimal fraction) = 0.52
C' = characteristic of the medium
= 0.7 m for a wide variety of media
K_T = $0.0057\,(1.1)^{(T-20)}$ where T is the water temperature in °C
L = length of system (parallel to flow path), m
W = width of system, m
d = design depth of system, m
n = porosity of system (as a decimal fraction)
= volume of voids/total volume
Q = average hydraulic loading on the system, m^3/day

$$= \frac{Q_{influent} + Q_{effluent}}{2}$$

The term "LWdn/Q" represents the hydraulic residence time, t. In a surface flow wetland, a portion of the available volume will be occupied by vegetation, so actual detention time will be a function of the remaining cross-sectional area available for flow. This can be defined as the porosity of the system in a manner similar to that used for soil systems. The product, dn, is equivalent to the depth of flow in a system with no vegetation present. In a vegetated system with perfect plug flow and no extraneous water losses or gains, it would also be the ratio of actual residence time to theoretical detention time. The A′ factor accounts for settleable BOD, removed near the head of the system.

When bed slope or hydraulic gradient is equal to 1% or greater, Reed et al.[46] use information from terrestrial overland flow systems to adjust the design model as follows:

$$\frac{C_x}{C_o} = 0.52 \exp\left[\frac{-C'\,K_T(A_V)^{1.75}{}_{LWdn}}{4.63S^{1/3}Q}\right] \tag{3}$$

where S is bed slope, or hydraulic gradient (as a decimal fraction).

Kadlec proposes different constants based on data from Houghton Lake and other wetland systems.[46] The equation is based on the Ergun equation, which adds a term to Darcy's law to account for turbulent flow. In terms of hydraulic residence time, the equation is:

$$t = \frac{L}{a^{1/b}\left(\frac{Q}{W}\right)^{1-1/b} S^{c/b}} \tag{4}$$

Based on data for the Houghton Lake wetland, b = 2.5–3.0 and c = 0.7–1.0. The coefficient a is site specific, but equal to 4×10^6 m/day for Houghton Lake for b = 3 and c = 1.

Flow through the system is augmented by precipitation and (negatively) evapotranspiration. Evapotranspiration slows the water and increases contact times. Rainfall has the opposite effect. For a wetland operated at constant depth, actual residence time is given by:

$$t_a = t\left[\frac{1}{\alpha}\ln\left(\frac{1}{1-\alpha}\right)\right] \tag{5}$$

where α is fractional augmentation and t is nominal residence time, based on nominal depth and wastewater addition rate. Fractional augmentation is the net fractional water gain or loss due to precipitation, evapotranspiration, and infiltration relative to wastewater flow (see Kadlec[46] for calculation information). Evapotranspiration strongly influences residence time, whereas rain has a lesser effect. At Houghton Lake and Listowel, the range in ratios of measured residence times to nominal residence time is 40–250%. The mean for Listowel, spanning all seasons over four years, was 126%. The mean for Houghton Lake was the nominal 100% because precipitation was equal to evapotranspiration for the chosen summer period.

Substituting Equation 5 in Equation 1 gives the following expression:

$$\frac{C_x}{C_o} = \left[1 - \alpha\frac{x}{L}\right]^{(K_T t/\alpha - 1)} \tag{6}$$

where x/L is the fractional distance to outlet.

If infiltration occurs, there is water loss as with evaporation, but the concentrating effect is not present. The corresponding expression is:

$$\frac{C_e}{C_o} = \left[1 - \alpha \frac{x}{L} \right]^{(K_T t/\alpha)} \tag{7}$$

Consideration of atmospheric phenomena reveals the hydrological complexity involved in optimizing design and performance of wetland treatment systems. Additional details and examples on use of these equations are provided by Reed et al.[46] and Kadlec.[66]

Organic Loading. Organic loading has been light on most systems evaluated. The relation between organic loading and BOD_5 removal rate suggests a linear correlation, at least up to loading rates of 100 kg/ha/day, the highest value reported for surface flow wetlands. Most wetland systems have operated at loading rates ranging from 18–116 kg BOD_5/ha/day and achieve 70–95% BOD_5 removal. Organic loading has not been used as a principal design criterion for constructed wetlands. It should be checked to ensure maintenance of aerobic conditions in the system. An upper limit of 110 kg/ha/day is suggested for this purpose.

Since most settleable BOD_5 will be removed close to the inlet, organic loading may be high on this small area. At Listowel, average organic loading over the surface area of system 4 was less than 12 kg/ha/day, with occasional anoxic conditions near the head. In a constructed wetland for polishing lagoon effluent in Gustine, California, this problem was solved with wastewater distribution at the head and at the one-third point in the channels with provisions for additional points if needed.[71]

Preliminary Treatment. Preliminary treatment to at least the primary level has been used for surface flow wetlands to keep organic loading within reasonable limits and avoid localized anaerobic conditions. These problems can be minimized with inlet structures that spread waste over much of the cell.

Constructed Wetlands with Subsurface Flow

Hydraulic Considerations. The hydraulic regime in fully saturated, fine-grained soils, sands, and gravels is controlled by hydraulic conductivity of the media and hydraulic gradient of the system as defined by Darcy's law:

$$Q = k_s AS \tag{8}$$

where k_s = hydraulic conductivity of a unit area of medium perpendicular to flow direction

A = cross-sectional area

Consistent units must be used for Q, k_s, and A. Equation 8 can be rearranged to solve for the saturated cross-sectional area of the system:

$$A = \frac{Q}{k_s S} \tag{9}$$

Flow through "clean" coarse gravels and rocks is more appropriately described by Ergun's equation:[46]

$$\rho g S = 150 \frac{\mu v (1 - \epsilon)^2}{D_p^2 \epsilon^2} + 1.75 \frac{\rho v^2 (1 - \epsilon)}{D_p \epsilon} \tag{10}$$

where ρ = density
g = gravitational acceleration
S = hydraulic gradient
μ = viscosity
ϵ = porosity
D_p = particle diameter
v = velocity = superficial velocity/ϵ

The term "pgS" is the kinetic energy of the flowing water. The difference between this equation and Darcy's law is the addition of a term to account for turbulent flow, which can occur for larger particle sizes. The equation would ordinarily be used in combination with the general relationship, Q = VA, to determine slope necessary for a given flow or, for a given slope and flow rate, to determine velocity and corresponding cross-sectional area required to preclude surface flow.

Typical values for initial porosities range from 0.18 to 0.35 for coarse gravel to fine gravel;[46] however, porosity may substantially change as the system matures, due to clogging and root development. This may result in laminar or transitional flow where Darcy's equation would be appropriate if mounding does not cause surface flow. Limited information precludes specific guidelines, though work in Europe indicates a long-term hydraulic conductivity of 10^{-3} m/s or more may be appropriate for gravel beds.[23] Unit flow velocity (Q/A) through the cross section should not exceed 8.6 m/day to avoid disruption of the medium-rhizome structure and to ensure sufficient contact time for treatment.[1]

Bed depth and type of vegetation should be matched to assure all flow will be within the root zone. Aerobic microsites in the root zone appear essential for effective treatment of organics and ammonia nitrogen. Present field experience on the depth of root penetration is limited to bulrushes, reeds, and cattails. Using data from the gravel system at Santee, bed depths should not exceed 60–76 cm for bulrushes and reeds, and 30 cm for cattails. The 60-cm depth for reeds has also been recommended for subsurface flow soil systems in West Germany,[1] so climate and substrate apparently are not factors in this relationship. In Europe, design depths are reduced by 50% for industrial wastes with high concentrations of refractory organics (COD).[1]

Experience in West Germany indicates three years' growth is necessary for full 60-cm penetration of reed rhizomes.[1] Partial draining for a few months in early fall for the first two years induces downward penetration of the rootstock. It is claimed that deeper penetration may not occur if beds are continuously saturated. A fully developed reed bed with root penetration to 60 cm in soil is claimed to have produced hydraulic conductivities of 260 $m^3/m^2/day$ when the original soil was less permeable clayey loam. Claimed hydraulic transformation by root and rhizome development is unverified, and the ability of reeds to produce hydraulic conductivity of this magnitude is doubtful.[23] When gravel or coarse sand is the medium, rhizome penetration is unnecessary to develop initial hydraulic properties of the bed. However, the root system may be critical in maintaining adequate long-term permeability (hydraulic conductivity). The root aerobic zone precludes anaerobic slimes from binding the substrate, and stabilized organics (including dead roots and rhizomes) supposedly stabilize the long-term permeability at a high level (260 $m^3/m^2/day$).[1] Performance of a gravel-bed system should improve during the first few years as root penetration brings oxygen to all parts of the bed.

Most soil systems are designed with a slope of 1% or slightly higher, but up to 8% may be used if local terrain permits. Bed slopes in gravel-bed systems are typically small (0–2%). Bed slopes are not equivalent to actual hydraulic gradients in most systems because reliable design values for hydraulic conductivity are not available and conductivity changes as systems mature.

Once bed depth and slope have been selected, bed width can be calculated based on Equations 9 or 10. Bed width is the cross-sectional area divided by bed depth. The cross-sectional area is independent of biochemical reactions and is controlled by hydraulic requirements. It is calculated directly by Equation 9 and indirectly by Equation 10 (velocity is calculated by Equation 10 and cross-sectional area is calculated by the general relationship $Q = VA$). For laminar flow (i.e., use of Darcy's law, Equation 9), hydraulic gradient of 1%, bed depth of 0.6 m, and long-term permeability of 260 m/day, the hydraulic loading per meter of inlet width (Q/W) is 1.56 $m^3/day/m$ (126 gpd/ft); e.g., a bed width of 64 m is needed for a flow of 100 m^3/day. The final dimension, bed length, is determined by the hydraulic residence time required for biological reactions to remove the desired level of contaminants (next section).

Consideration of changes in flow hydraulics as the system matures and other practical system limitations indicates that the length-width ratios will be relatively small to assure subsurface flow over the long term. For gravel beds, the ratio will be less than 3:1 and perhaps less than 1:1. The ratios for soil beds will be smaller.

Biological Relationships. Removal of biodegradable constituents such as BOD_5 and organic nitrogen can be described with first-order, plug-flow kinetics:

$$\frac{C_e}{C_o} = \exp\,[-K_T t] \qquad (1)$$

Hydraulic residence time is a function of available void spaces (V_v) and average flow rate through the system:

$$t = \frac{V_v}{Q} \qquad (11)$$

where $V_v = LWdn$

To avoid design errors, average flow through the system must consider water losses due to evapotranspiration and seepage, and/or water gains due to precipitation.[46] Typical values for initial porosity range from 18% to 35% for coarse gravel to fine gravel and 37% to 44% for coarse sand to fine sand;[46] however, porosity may change from clogging and root development as the system ages. With time, much of the flow may be in the debris layer on top of the bed.

Since the product LW is equal to the surface area, A_s, the basic equation can be written as:

$$\frac{C_e}{C_o} = \exp\left[\frac{-K_T A_s dn}{Q}\right] \qquad (12)$$

The temperature dependence of the rate constant for BOD_5 is described by:

$$K_T = K_{20}(1.1)^{(T-20)} \qquad (13)$$

where K_{20} = rate constant at 20°C

Based on limited information from few systems,[1,18,72] the rate constant, K_{20}, for a particular system may be related to the porosity of the bed medium. This is reasonable because natural soils with high porosities have finer void spaces, providing more opportunity for surface contact compared to a more permeable gravel. The tentative relationship proposed by Reed et al.[46] is:

$$K_{20} = K_o(37.31n)^{4.172} \qquad (14)$$

where K_o = the "optimum" rate constant for a medium with a fully developed root zone, $days^{-1}$
= 1.839 $days^{-1}$ for typical municipal wastewaters
= 0.198 $days^{-1}$ for industrial wastewaters with high COD

Using typical porosity values in this expression, gravel-bed systems will have a kinetic rate constant one-third to one-fourth of finer-textured sands. This difference in kinetic rate constants translates into larger surface area requirements for gravel beds.

The relationship described by Equation 14 and the K_o values is tentative and should only be used for preliminary design estimates. Further study is needed on the biological kinetics in subsurface flow wetlands.

Organic Loading. Organic loading is not used as a critical design parameter, but rather as a check to ensure sufficient oxygen will be present in the subsurface bed to sustain intended treatment reactions. Commonly used emergent plants can transmit from 5 to 45 g O_2/day/m^2 of wetland surface.[1,73]

Assuming that oxygen required is equivalent to that for partial-mix aerated ponds and a conservative oxygen loss rate for plants of 20 g/m^2/day, the oxygen balance in a subsurface flow wetland can be checked with Equations 15 and 16.

$$\text{Required } O_2 = 1.5\ L_o \tag{15}$$

$$\text{Available } O_2 = \frac{(TrO_2)(A_s)}{1000\ \text{g/kg}} \tag{16}$$

where O_2 = oxygen required or available, kg/day
L_o = organic (BOD_5) loading, kg/day
TrO_2 = oxygen transfer rate for the vegetation
= 20 g/(m^2/day)

As a further safety factor, available oxygen determined from Equation 16 should be twice the oxygen requirements. Units processing high-strength wastewaters need increased operational surface area to achieve this balance.

At the 20 g/m^2/day oxygen supply rate, organic loading could be up to 133 kg BOD_5/ha/day, similar to values for surface flow wetlands. At the theoretical maximum oxygen transfer rate (45 g/m^2/day), organic loading could be as high as 300 kg/ha/day.

Preliminary Treatment. Subsurface flow wetlands in the United States use at least primary treatment prior to constructed wetlands. Primary treatment options include septic tanks, Imhoff tanks, primary clarifiers, and lagoons. Anaerobic reactors could be used to reduce organic and solids content of high-strength industrial wastewaters. If phosphorus removal is required and gravel or coarse sand is used for bed media, a preliminary or posttreatment method for phosphorus removal must be included.

Small length-width ratios are better for high organic loading because unit loading at the inlet is reduced. Most European systems use small ratios (less than 1:1), and many apply screened and degritted wastewater to the inlet zone. Fully developed wetlands are claimed to have rapid solids removal and decomposition and no odor problem.[1]

Appendix B

Data Summary Tables

Surface Water Quality Data - B-1
Groundwater Quality Data - B-2
Soil Data - B-3
Vegetation Data - B-4

Appendix B-1

Surface Water Quality Data and Discussion of Metals Concentrations

PARAMETER: Suspended solids INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	15	0	15	15	3
12/12/89	22	5	0	5	6	3
01/02/90	43	5	0	5	5	1
01/09/90	50	10	1	9	12	3
01/16/90	57	5	0	5	5	3
01/23/90	64	5	0	5	5	3
01/31/90	72	5	0	5	5	3
02/05/90	77	7	3	5	12	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	10	6	5	18	3
03/06/90	106	5	0	5	5	3
03/12/90	112	no data				0
03/19/90	119	6	1	5	7	3
03/26/90	126	9	2	8	12	3
04/03/90	134	32	23	5	62	3
04/10/90	141	6	0	5	6	3
04/16/90	147	5	0	5	5	3
04/23/90	154	5	0	5	6	3
04/30/90	161	5	0	5	5	3
05/08/90	169	5	0	5	5	3
05/14/90	175	5	0	5	5	3
05/22/90	183	5	0	5	5	3
05/25/90	186	5	0	5	5	3
06/04/90	196	5	0	5	5	3
06/11/90	203	7	0	7	8	3
06/18/90	210	5	0	5	5	3
06/25/90	217	5	0	5	5	3
07/03/90	225	5	0	5	5	3
07/09/90	231	5	0	5	5	3
07/16/90	238	5	0	5	5	3
07/23/90	245	5	0	5	5	3
07/30/90	252	19	19	5	46	3
08/08/90	261	5	0	5	5	3
08/13/90	266	5	0	5	5	3
08/20/90	273	10	0	10	10	3
08/27/90	280	9	0	9	10	3
09/04/90	288	5	0	5	5	3
09/10/90	294	5	0	5	5	3
09/17/90	301	5	0	5	5	3
09/25/90	309	10	0	10	10	3
10/02/90	316	13	5	9	20	3
10/09/90	323	10	0	10	10	3
10/16/90	330	10	0	10	10	3
10/22/90	336	10	0	10	10	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	52	2	49	54	3
02/11/91	448					0
02/18/91	455	8	0	8	9	3
02/25/91	462					0
03/04/91	469	5	0	5	5	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	5	0	5	5	3
03/31/91	496	5	0	5	5	3
OVERALL		9	9	5	62	136
C.V.		108.7%				

PARAMETER: Suspended solids MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	5	0	5	5	3
12/12/89	22	5	0	5	5	3
01/02/90	43	5	0	5	5	1
01/09/90	50	5	0	5	5	3
01/16/90	57	5	0	5	5	3
01/23/90	64	28	5	23	34	3
01/31/90	72	122	26	85	141	3
02/05/90	77	18	9	7	29	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	5	0	5	5	3
03/06/90	106	106	21	82	133	3
03/12/90	112	no data				0
03/19/90	119	12	10	5	27	3
03/26/90	126	7	1	6	8	3
04/03/90	134	10	4	5	15	3
04/10/90	141	5	0	5	5	3
04/16/90	147	5	0	5	5	3
04/23/90	154	5	0	5	5	3
04/30/90	161	24	12	8	35	3
05/08/90	169	5	0	5	5	3
05/14/90	175	24	12	8	35	3
05/22/90	183	5	0	5	5	3
05/25/90	186	9	2	7	12	3
06/04/90	196	8	2	6	10	3
06/11/90	203	7	3	5	11	3
06/18/90	210	5	0	5	5	3
06/25/90	217	5	0	5	5	3
07/03/90	225	5	0	5	5	3
07/09/90	231	5	0	5	5	3
07/16/90	238	5	0	5	5	3
07/23/90	245	5	0	5	5	3
07/30/90	252	22	24	5	55	3
08/08/90	261	5	0	5	5	3
08/13/90	266	5	0	5	5	3
08/20/90	273	10	0	10	10	3
08/27/90	280	10	0	10	10	3
09/04/90	288	5	0	5	5	3
09/10/90	294	5	0	5	5	3
09/17/90	301	5	0	5	5	3
09/25/90	309	10	0	10	10	3
10/02/90	316	10	0	10	10	3
10/09/90	323	10	0	10	10	3
10/16/90	330	10	0	9	10	3
10/22/90	336	10	0	10	10	3
11/05/90 to	350					0
01/28/91						0
02/04/91	441	5	0	5	5	3
02/11/91	448					0
02/18/91	455	5	0	5	5	3
02/25/91	462					0
03/04/91	469	5	0	5	5	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	5	0	5	5	3
03/31/91	496	5	0	5	5	3
OVERALL		13	23	5	141	136
C.V.		183.0%				

PARAMETER: Suspended solids EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	5	0	5	5	3
12/12/89	22	5	0	5	5	3
01/02/90	43	5	0	5	5	1
01/09/90	50	5	0	5	5	3
01/16/90	57	5	0	5	5	3
01/23/90	64	5	0	5	5	3
01/31/90	72	5	0	5	5	3
02/05/90	77	5	0	5	5	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	7	2	5	10	3
03/06/90	106	8	2	5	11	3
03/12/90	112	no data				0
03/19/90	119	5	0	5	5	3
03/26/90	126	10	3	7	14	3
04/03/90	134	8	3	5	12	3
04/10/90	141	8	3	5	12	3
04/16/90	147	6	1	5	7	3
04/23/90	154	5	0	5	5	3
04/30/90	161	6	1	5	8	3
05/08/90	169	5	0	5	5	3
05/14/90	175	6	1	5	8	3
05/22/90	183	5	0	5	5	3
05/25/90	186	5	0	5	5	3
06/04/90	196	7	1	6	8	3
06/11/90	203	5	0	5	5	3
06/18/90	210	5	0	5	5	3
06/25/90	217	6	0	5	6	3
07/03/90	225	7	0	6	7	3
07/09/90	231	6	1	5	7	3
07/16/90	238	5	0	5	5	3
07/23/90	245	5	0	5	5	3
07/30/90	252	5	0	5	6	3
08/08/90	261	5	0	5	5	2
08/13/90	266	8	1	7	10	3
08/20/90	273	10	0	10	10	3
08/27/90	280	10	0	10	10	3
09/04/90	288	5	0	5	5	3
09/10/90	294	5	0	5	5	3
09/17/90	301	5	0	5	6	3
09/25/90	309	10	0	10	10	3
10/02/90	316	10	0	10	10	3
10/09/90	323	10	0	10	10	3
10/16/90	330	10	0	10	10	3
10/22/90	336	10	0	10	10	3
11/05/90 to	350					0
01/28/91						0
02/04/91	441	5	0	5	5	3
02/11/91	448					0
02/18/91	455	5	0	5	5	3
02/25/91	462					0
03/04/91	469	5	0	5	5	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	5	0	5	5	3
03/31/91	496	7	3	5	12	3
OVERALL		6	2	5	14	135
C.V.		34.1%				

PARAMETER: pH INFLUENT units: -

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	7.2	0.0	7.2	7.3	3
12/12/89	22	7.2	0.0	7.2	7.3	3
01/02/90	43	7.5	0.3	7.1	7.8	3
01/09/90	50	7.3	0.1	7.2	7.4	3
01/16/90	57	7.4	0.2	7.2	7.7	3
01/23/90	64	7.2	0.2	7.0	7.5	3
01/31/90	72	7.0	0.0	7.0	7.1	3
02/05/90	77	7.0	0.1	6.9	7.1	3
02/12/90	84	no data: winter freeze-up				0
02/19/90	91					0
02/27/90	99	7.0	0.0	7.0	7.0	3
03/06/90	106	7.0	0.0	7.0	7.1	3
03/12/90	112	no data				0
03/19/90	119	7.2	0.0	7.1	7.2	3
03/26/90	126	7.3	0.0	7.3	7.3	3
04/03/90	134	7.5	0.0	7.5	7.6	3
04/10/90	141	7.4	0.0	7.4	7.4	3
04/16/90	147	7.5	0.0	7.5	7.5	3
04/23/90	154	7.6	0.0	7.5	7.6	3
04/30/90	161	7.7	0.1	7.6	7.8	3
05/08/90	169	7.8	0.2	7.5	8.1	3
05/14/90	175	7.7	0.1	7.6	7.8	3
05/22/90	183	7.8	0.0	7.8	7.8	3
05/25/90	186	7.7	0.0	7.7	7.7	3
06/04/90	196	7.7	0.0	7.7	7.7	3
06/11/90	203	7.7	0.2	7.5	7.9	3
06/18/90	210	8.0	0.0	7.9	8.0	3
06/25/90	217	8.0	0.1	7.8	8.1	3
07/03/90	225	8.2	0.0	8.1	8.2	3
07/09/90	231	7.9	0.1	7.7	8.0	3
07/16/90	238	7.8	0.1	7.7	7.9	3
07/23/90	245	8.1	0.0	8.1	8.1	3
07/30/90	252	8.2	0.0	8.2	8.3	3
08/06/90	259	7.9	0.1	7.8	8.1	3
08/13/90	266	8.0	0.0	8.0	8.0	3
08/20/90	273	8.0	0.0	7.9	8.0	3
08/27/90	280	8.0	0.1	7.9	8.2	3
09/04/90	288	8.0	0.0	7.9	8.0	3
09/10/90	294	8.0	0.0	7.9	8.0	3
09/18/90	302	7.9	0.0	7.9	7.9	3
09/25/90	309	7.9	0.0	7.8	7.9	3
10/02/90	316	7.9	0.0	7.9	7.9	3
10/09/90	323	8.1	0.0	8.1	8.1	3
10/16/90	330	8.0	0.1	7.9	8.1	3
10/22/90	336	8.1	0.0	8.1	8.1	3
11/05/90 to	350					0
01/28/91						0
02/04/91	441	7.7	0.0	7.7	7.7	3
02/11/91	448					0
02/18/91	455	7.7	0.0	7.7	7.8	3
02/25/91	462					0
03/04/91	469	7.7	0.0	7.7	7.8	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	7.8	0.0	7.8	7.8	3
03/31/91	496	7.9	0.0	7.9	7.9	3
OVERALL		7.7	0.4	6.9	8.3	141
C.V.		4.8%				

PARAMETER: pH MIDPOINT units: -

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	7.6	0.2	7.4	7.8	3
12/12/89	22	7.3	0.0	7.3	7.4	3
01/02/90	43	7.7	0.5	7.0	8.0	3
01/09/90	50	7.3	0.2	7.1	7.5	3
01/16/90	57	7.4	0.1	7.3	7.5	3
01/23/90	64	7.4	0.3	7.2	7.8	3
01/31/90	72	7.0	0.0	6.9	7.0	3
02/05/90	77	7.[illegible]	0.1	7.1	7.3	3
02/12/90	84	no data: winter freeze-up				0
02/19/90	91					0
02/27/90	99	7.5	0.4	6.9	7.9	3
03/06/90	106	7.3	0.0	7.3	7.4	3
03/12/90	112	no data				0
03/19/90	119	7.4	0.1	7.3	7.6	3
03/26/90	126	7.3	0.3	7.1	7.8	3
04/03/90	134	7.4	0.2	7.2	7.6	3
04/10/90	141	7.0	0.2	6.9	7.3	3
04/16/90	147	7.0	0.0	7.0	7.0	3
04/23/90	154	7.1	0.0	7.1	7.2	3
04/30/90	161	7.3	0.2	7.1	7.6	3
05/08/90	169	7.2	0.1	7.1	7.3	3
05/14/90	175	7.3	0.2	7.1	7.6	3
05/22/90	183	7.1	0.0	7.1	7.1	3
05/25/90	186	7.0	0.0	7.0	7.0	3
06/04/90	196	7.1	0.0	7.1	7.1	3
06/11/90	203	7.5	0.3	7.2	8.0	3
06/18/90	210	7.8	0.0	7.6	8.0	3
06/25/90	217	7.7	0.4	7.4	8.2	3
07/03/90	225	8.0	0.2	7.8	8.3	3
07/09/90	231	8.0	0.3	7.5	8.3	3
07/16/90	238	8.1	0.0	8.1	8.1	3
07/23/90	245	8.0	0.1	7.8	8.1	3
07/30/90	252	8.1	0.1	8.0	8.2	3
08/06/90	259	8.0	0.0	7.9	8.0	3
08/13/90	266	7.9	0.2	7.7	8.2	3
08/20/90	273	7.7	0.0	7.7	7.8	3
08/27/90	280	7.7	0.0	7.7	7.8	3
09/04/90	288	7.8	0.0	7.8	7.8	3
09/10/90	294	7.8	0.0	7.8	7.8	3
09/18/90	302	7.6	0.0	7.6	7.6	3
09/25/90	309	7.6	0.0	7.6	7.7	3
10/02/90	316	7.6	0.0	7.5	7.6	3
10/09/90	323	7.9	0.0	7.8	7.9	3
10/16/90	330	7.7	0.0	7.7	7.7	3
10/22/90	336	8.0	0.2	7.8	8.2	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	7.4	0.0	7.3	7.4	3
02/11/91	448					0
02/18/91	455	7.5	0.1	7.4	7.7	3
02/25/91	462					0
03/04/91	469	7.6	0.0	7.6	7.6	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	7.8	0.0	7.8	7.8	3
03/31/91	496	7.4	0.0	7.4	7.4	3
OVERALL		7.5	0.4	6.9	8.3	141
C.V.		4.8%				

PARAMETER: pH EFFLUENT units: -

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	7.9	0.2	7.8	8.0	3
12/12/89	22	7.3	0.1	7.2	7.4	3
01/02/90	43	7.6	0.4	7.0	7.9	3
01/09/90	50	7.4	0.2	7.2	7.7	3
01/16/90	57	7.3	0.1	7.1	7.4	3
01/23/90	64	7.2	0.1	7.1	7.3	3
01/31/90	72	7.1	0.1	7.0	7.2	3
02/05/90	77	7.2	0.1	7.0	7.3	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	7.1	0.0	7.1	7.1	1
03/06/90	106	7.8	0.0	7.7	7.8	3
03/12/90	112	no data				0
03/19/90	119	7.1	0.0	7.0	7.1	3
03/26/90	126	6.7	0.0	6.7	6.8	3
04/03/90	134	7.1	0.2	6.9	7.3	3
04/10/90	141	7.3	0.4	6.9	7.9	3
04/16/90	147	6.7	0.0	6.6	6.7	3
04/23/90	154	7.0	0.1	6.8	7.1	3
04/30/90	161	6.7	0.0	6.7	6.7	3
05/08/90	169	6.9	0.0	6.8	7.0	3
05/14/90	175	6.7	0.0	6.7	6.7	3
05/22/90	183	7.2	0.0	7.2	7.3	3
05/25/90	186	7.1	0.0	7.1	7.1	3
06/04/90	196	7.2	0.0	7.2	7.2	3
06/11/90	203	7.7	0.2	7.6	8.0	3
06/18/90	210	7.8	0.0	7.7	7.9	3
06/25/90	217	7.8	0.0	7.5	8.2	3
07/03/90	225	8.1	0.0	7.7	8.3	3
07/09/90	231	7.8	0.4	7.4	8.3	3
07/16/90	238	8.0	0.1	7.9	8.1	3
07/23/90	245	7.8	0.2	7.6	8.0	3
07/30/90	252	7.9	0.0	7.6	8.2	3
08/06/90	259	7.9	0.0	7.8	8.0	3
08/13/90	266	7.9	0.1	7.8	8.1	3
08/20/90	273	7.5	0.0	7.4	7.6	3
08/27/90	280	7.6	0.0	7.6	7.6	3
09/04/90	288	7.7	0.0	7.7	7.7	3
09/10/90	294	7.7	0.0	7.7	7.7	3
09/18/90	302	7.6	0.0	7.5	7.6	3
09/25/90	309	7.5	0.0	7.5	7.5	3
10/02/90	316	7.5	0.0	7.5	7.5	3
10/09/90	323	7.6	0.0	7.6	7.6	3
10/16/90	330	7.8	0.1	7.7	7.9	3
10/22/90	336	7.7	0.1	7.6	7.9	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	6.7	0.0	6.7	6.7	3
02/11/91	448					0
02/18/91	455	7.4	0.0	7.4	7.5	3
02/25/91	462					0
03/04/91	469	7.2	0.0	7.2	7.2	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	7.1	0.0	7.1	7.1	3
03/31/91	496	7.1	0.0	7.1	7.2	3
OVERALL		7.4	0.4	6.6	8.3	139
C.V.		5.6%				

PARAMETER: Conductivity INFLUENT units: umho/cm

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	1330	8	1320	1340	3
12/12/89	22	1330	0	1330	1330	3
01/02/90	43	1208	52	1140	1267	3
01/09/90	50	530	6	524	539	3
01/16/90	57	614	10	600	625	3
01/23/90	64	1350	0	1350	1350	3
01/31/90	72	534	6	525	539	3
02/05/90	77	580	3	577	585	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	1001	5	994	1007	3
03/06/90	106	609	8	602	620	3
03/12/90	112	no data				0
03/19/90	119	652	7	643	661	3
03/26/90	126	855	1	854	857	3
04/03/90	134	1027	5	1020	1032	3
04/10/90	141	1161	19	1141	1187	3
04/16/90	147	1142	10	1131	1156	3
04/23/90	154	1340	8	1330	1350	3
04/30/90	161	1637	5	1630	1640	3
05/08/90	169	1430	0	1430	1430	3
05/14/90	175	1637	5	1630	1640	3
05/22/90	183	1493	12	1480	1510	3
05/25/90	186	1470	0	1470	1470	3
06/04/90	196	1463	5	1460	1470	3
06/11/90	203	863	5	858	869	3
06/18/90	210	975	4	970	981	3
06/25/90	217	1437	9	1430	1450	3
07/03/90	225	1827	5	1820	1830	3
07/09/90	231	2027	12	2010	2040	3
07/16/90	238	1870	24	1840	1900	3
07/23/90	245	2003	21	1960	2030	3
07/30/90	252	1953	9	1940	1960	3
08/08/90	261	2183	24	2150	2200	3
08/13/90	266	2277	21	2250	2300	3
08/20/90	273	2210	42	2180	2270	3
08/27/90	280	2343	25	2310	2370	3
09/04/90	288	2323	61	2250	2400	3
09/10/90	294	2323	61	2250	2400	3
09/18/90	302	2303	50	2250	2370	3
09/25/90	309	2340	16	2320	2360	3
10/02/90	316	2693	9	2680	2700	3
10/09/90	323	2617	9	2610	2630	3
10/16/90	330	2263	9	2250	2270	3
10/22/90	336	2307	12	2290	2320	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	1817	5	1810	1820	3
02/11/91	448					0
02/18/91	455	2370	8	2360	2380	3
02/25/91	462					0
03/04/91	469	2523	5	2520	2530	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	2703	12	2690	2720	3
03/31/91	496	2757	9	2750	2770	3
OVERALL		1625	651	524	2720	138
C.V.		40.1%				

PARAMETER: Conductivity MIDPOINT units: umho/cm

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	1076	41	1018	1109	3
12/12/89	22	1145	20	1117	1161	3
01/02/90	43	1098	54	1025	1155	3
01/09/90	50	810	3	808	814	3
01/16/90	57	624	2	622	626	3
01/23/90	64	674	2	672	677	3
01/31/90	72	715	4	710	720	3
02/05/90	77	607	6	598	612	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	835	25	802	862	3
03/06/90	106	539	3	535	542	3
03/12/90	112	no data				0
03/19/90	119	545	5	539	550	3
03/26/90	126	745	2	742	748	3
04/03/90	134	858	10	844	866	3
04/10/90	141	1034	3	1030	1037	3
04/16/90	147	1086	4	1081	1090	3
04/23/90	154	1135	15	1119	1155	3
04/30/90	161	1223	5	1217	1230	3
05/08/90	169	1335	28	1296	1360	3
05/14/90	175	1223	5	1217	1230	3
05/22/90	183	1278	3	1275	1282	3
05/25/90	186	1420	0	1420	1420	3
06/04/90	196	1276	0	1276	1277	3
06/11/90	203	1123	45	1060	1160	3
06/18/90	210	1057	0	1040	1070	3
06/25/90	217	1327	5	1320	1330	3
07/03/90	225	1483	31	1440	1510	3
07/09/90	231	1743	9	1730	1750	3
07/16/90	238	1773	12	1760	1790	3
07/23/90	245	1910	0	1910	1910	3
07/30/90	252	1977	9	1970	1990	3
08/08/90	261	2170	33	2130	2210	3
08/13/90	266	2220	14	2210	2240	3
08/20/90	273	2177	17	2160	2200	3
08/27/90	280	2273	9	2260	2280	3
09/04/90	288	2163	59	2080	2210	3
09/10/90	294	2163	59	2080	2210	3
09/18/90	302	2327	61	2240	2370	3
09/25/90	309	2393	12	2380	2410	3
10/02/90	316	2313	12	2300	2330	3
10/09/90	323	2043	5	2040	2050	3
10/16/90	330	2240	8	2230	2250	3
10/22/90	336	2253	17	2230	2270	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	1006	62	919	1060	3
02/11/91	448					0
02/18/91	455	2077	58	2000	2140	3
02/25/91	462					0
03/04/91	469	2410	14	2390	2420	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	2600	8	2590	2610	3
03/31/91	496	2573	5	2570	2580	3
OVERALL		1496	627	535	2610	138
C.V.		41.9%				

PARAMETER: Conductivity EFFLUENT units: umho/cm

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	991	9	978	1000	3
12/12/89	22	1097	6	1090	1104	3
01/02/90	43	1138	40	1082	1168	3
01/09/90	50	774	8	763	779	3
01/16/90	57	712	26	675	733	3
01/23/90	64	688	14	670	703	3
01/31/90	72	701	20	675	725	3
02/05/90	77	481	65	394	549	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	798	10	784	808	3
03/06/90	106	521	2	518	523	3
03/12/90	112	no data				0
03/19/90	119	557	3	553	559	3
03/26/90	126	582	10	571	595	3
04/03/90	134	753	6	745	759	3
04/10/90	141	1058	120	888	1149	3
04/16/90	147	906	9	893	914	3
04/23/90	154	943	32	907	985	3
04/30/90	161	1015	4	1009	1019	3
05/08/90	169	1067	0	1064	1069	3
05/14/90	175	1015	4	1009	1019	3
05/22/90	183	1150	1	1149	1152	3
05/25/90	186	1360	0	1360	1360	3
06/04/90	196	1192	0	1191	1192	3
06/11/90	203	1004	17	981	1020	3
06/18/90	210	1170	0	1150	1190	3
06/25/90	217	1223	0	1220	1230	3
07/03/90	225	1203	0	1180	1220	3
07/09/90	231	1390	50	1320	1430	3
07/16/90	238	1560	8	1550	1570	3
07/23/90	245	1627	9	1620	1640	3
07/30/90	252	1713	0	1670	1740	3
08/08/90	261	1853	0	1840	1870	3
08/13/90	266	2043	9	2030	2050	3
08/20/90	273	2107	0	2050	2210	3
08/27/90	280	2283	19	2270	2310	3
09/04/90	288	2053	21	2030	2080	3
09/10/90	294	2053	21	2030	2080	3
09/18/90	302	2437	12	2420	2450	3
09/25/90	309	2400	8	2390	2410	3
10/02/90	316	2153	21	2130	2180	3
10/09/90	323	2040	78	1930	2100	3
10/16/90	330	2153	45	2090	2190	3
10/22/90	336	2080	71	1980	2140	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	364	23	333	388	3
02/11/91	448					0
02/18/91	455	1593	24	1560	1610	3
02/25/91	462					0
03/04/91	469	2247	5	2240	2250	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	2333	17	2310	2350	3
03/31/91	496	2433	9	2420	2440	3
OVERALL		1367	614	333	2450	138
C.V.		44.9%				

PARAMETER: Diss. Organic Carbon INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	4.333	0.471	4.000	5.000	3
12/12/89	22	18.667	2.055	16.000	21.000	3
01/02/90	43					0
01/09/90	50	10.667	2.055	8.000	13.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	4.333	0.471	4.000	5.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				3
03/19/90	119					0
03/26/90	126					0
04/03/90	134					0
04/10/90	141	17.333	18.856	4.000	44.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	4.667	0.471	4.000	5.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	7.000	0.816	6.000	8.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	6.333	0.943	5.000	7.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252					0
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	7.000	0.000	7.000	7.000	3
09/10/90	294					0
09/18/90	302					0
09/25/90	309					0
10/02/90	316	7.000	2.160	5.000	10.000	3
10/09/90 to	323					0
02/11/91	448					0
02/18/91	455	4.333	0.471	4.000	5.000	3
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	4.333	0.471	4.000	5.000	3
OVERALL		7.944	7.393	3.000	44.000	36
C.V.		93.06%				

PARAMETER: Dissolved Organic Carbon MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	7.667	2.055	5.000	10.000	3
12/12/89	22	13.000	6.683	6.000	22.000	3
01/02/90	43					0
01/09/90	50	10.333	0.471	10.000	11.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	6.333	1.700	4.000	8.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119					0
03/26/90	126					0
04/03/90	134					0
04/10/90	141	20.667	23.570	4.000	54.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	4.333	0.471	4.000	5.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	10.667	1.247	9.000	12.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	6.667	0.471	6.000	7.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252					0
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	4.333	0.471	4.000	5.000	3
09/10/90	294					0
09/18/90	302					0
09/25/90	309					0
10/02/90	316	12.333	0.471	12.000	13.000	3
10/09/90 to	323					0
02/11/91	448					0
02/18/91	455	3.333	0.471	3.000	4.000	3
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	5.333	0.471	5.000	6.000	3
OVERALL		8.667	8.622	3.000	54.000	36
C.V.		0.995				

PARAMETER: Dissolved Organic Carbon EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	9.333	0.943	8.000	10.000	3
12/12/89	22	15.667	3.091	13.000	20.000	3
01/02/90	43					0
01/09/90	50	10.333	1.247	9.000	12.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	4.667	1.247	3.000	6.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119					0
03/26/90	126					0
04/03/90	134					0
04/10/90	141	7.333	0.471	7.000	8.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	6.000	0.000	6.000	6.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	10.000	0.000	10.000	10.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	11.000	0.000	11.000	11.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252					0
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	7.667	0.471	7.000	8.000	3
09/10/90	294					0
09/18/90	302					0
09/25/90	309					0
10/02/90	316	13.000	0.000	13.000	13.000	3
10/09/90 to	323					0
02/11/91	448					0
02/18/91	455	4.333	0.471	4.000	5.000	3
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	6.667	0.471	6.000	7.000	3
OVERALL		8.694	3.542	3.000	20.000	36
C.V.		40.74%				

AMMONIA - NITROGEN INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No.
	0					
12/12/89	22	0.114	0.030	0.074	0.148	3
01/02/90	43	0.119	0.006	0.114	0.127	3
01/09/90	50	0.119	0.006	0.114	0.127	3
01/16/90	57	0.031	0.003	0.028	0.036	3
01/24/90	65	0.048	0.007	0.039	0.057	3
01/31/90	72	0.005	0.003	0.002	0.009	3
02/05/90	77	0.036	0.007	0.026	0.043	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	0.053	0.004	0.047	0.056	3
03/05/90	105	0.070	0.008	0.058	0.078	3
03/12/90	112	no data				0
03/19/90	119	0.183	0.005	0.176	0.188	3
03/26/90	126	0.182	0.004	0.177	0.186	3
04/03/90	134	0.089	0.013	0.071	0.101	3
04/10/90	141	0.057	0.002	0.054	0.059	3
04/16/90	147	0.054	0.003	0.050	0.058	3
04/23/90	154	0.050	0.001	0.048	0.051	3
04/30/90	161	0.047	0.000	0.047	0.047	3
05/08/90	169	0.089	0.008	0.082	0.100	3
05/14/90	175	0.020	14.000	0.020	0.021	3
05/22/90	183	0.038	0.001	0.037	0.040	3
05/25/90	186	0.014	0.006	0.007	0.022	3
05/28/90	189					
06/04/90	196	0.025	0.021	0.009	0.054	3
06/11/90	203	0.012	0.000	0.012	0.013	3
06/18/90	210	0.014	0.000	0.012	0.018	3
06/25/90	217	0.091	0.003	0.089	0.095	3
07/03/90	225	0.195	0.007	0.189	0.205	3
07/09/90	231	0.177	0.003	0.172	0.180	3
07/16/90	238	0.261	0.001	0.260	0.263	3
07/23/90	245	0.294	0.002	0.292	0.296	3
07/30/90	252	0.340	0.013	0.329	0.359	3
08/08/90	261	0.333	0.006	0.328	0.341	3
08/13/90	266	0.238	0.001	0.237	0.239	3
08/20/90	273	0.280	0.015	0.268	0.301	3
08/27/90	280	0.287	0.000	0.287	0.287	3
09/04/90	288	0.267	0.002	0.264	0.269	3
09/10/90	294	0.131	0.001	0.130	0.132	3
09/18/90	302	0.047	0.001	0.046	0.048	3
09/25/90	309	0.016	0.001	0.014	0.017	3
10/02/90	316	0.234	0.012	0.220	0.250	3
10/09/90	323	0.343	0.003	0.339	0.345	3
10/16/90	330	0.362	0.002	0.360	0.364	3
10/22/90	336	0.388	0.010	0.380	0.402	3
11/05/90 to	350	project shut down due to funding cut				0
01/28/91	434					0
02/04/91	441	0.427	0.012	0.415	0.444	3
02/11/91	448					0
02/18/91	455	0.361	0.007	0.355	0.371	3
02/25/91	462					0
03/04/91	469	0.275	0.004	0.270	0.280	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.220	0.003	0.216	0.222	3
03/31/91	496	0.190	0.007	0.184	0.200	3
OVERALL		0.155	0.127	0.002	0.444	135
C.V.		81.91%				

AMMONIA - NITROGEN MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0					
12/12/89	22	0.159	0.101	0.070	0.300	3
01/02/90	43	0.173	0.002	0.170	0.176	3
01/09/90	43	0.173	0.002	0.170	0.176	3
01/16/90	57	0.106	0.034	0.078	0.154	3
01/24/90	65	0.127	0.007	0.120	0.137	3
01/31/90	72	0.455	0.354	0.035	0.900	3
02/05/90	77	0.011	0.011	0.002	0.026	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	0.064	0.051	0.002	0.128	3
03/05/90	105	0.212	0.093	0.085	0.304	3
03/12/90	112	no data				0
03/19/90	119	0.032	0.021	0.009	0.060	3
03/26/90	126	0.033	0.000	0.027	0.037	3
04/03/90	134	0.048	0.000	0.012	0.089	3
04/10/90	141	0.049	0.007	0.044	0.059	3
04/16/90	147	0.104	0.063	0.052	0.192	3
04/23/90	154	0.049	0.008	0.037	0.056	3
04/30/90	161	0.104	0.021	0.083	0.132	3
05/08/90	169	0.132	0.028	0.110	0.171	3
05/14/90	175	0.065	0.006	0.060	0.074	3
05/22/90	183	0.082	0.002	0.079	0.085	3
05/25/90	186	0.089	0.011	0.077	0.104	3
05/28/90	189	no data				0
06/04/90	196	0.012	0.002	0.009	0.015	3
06/11/90	203	0.088	0.023	0.061	0.117	3
06/18/90	210	0.020	0.000	0.011	0.034	3
06/25/90	217	0.091	0.001	0.090	0.093	3
07/03/90	225	0.144	0.000	0.133	0.154	3
07/09/90	231	0.115	0.000	0.114	0.115	3
07/16/90	238	0.199	0.003	0.195	0.203	3
07/23/90	245	0.103	0.001	0.102	0.104	3
07/30/90	252	0.066	0.004	0.061	0.070	3
08/08/90	261	0.209	0.090	0.110	0.328	3
08/13/90	266	0.055	0.002	0.052	0.056	3
08/20/90	273	0.084	0.000	0.081	0.087	3
08/27/90	280	0.133	0.017	0.110	0.150	3
09/04/90	288	0.147	0.000	0.025	0.390	3
09/10/90	294	0.062	0.000	0.050	0.072	3
09/18/90	302	0.058	0.004	0.054	0.064	3
09/25/90	309	0.064	0.000	0.062	0.068	3
10/02/90	316	0.084	0.005	0.080	0.092	3
10/09/90	323	0.049	0.022	0.023	0.076	3
10/16/90	330	0.064	0.011	0.056	0.080	3
10/22/90	336	0.058	0.006	0.052	0.066	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.177	0.054	0.100	0.220	3
02/11/91	448					0
02/18/91	455	0.087	0.016	0.071	0.109	3
02/25/91	462					0
03/04/91	469	0.033	0.005	0.026	0.038	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.008	0.003	0.004	0.010	3
03/31/91	496	0.013	0.002	0.010	0.015	3
OVERALL		0.096814815	0.098	0.002	0.900	135
C.V.		1.013				

AMMONIA - NITOGEN EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
12/12/89	22	0.404	0.028	0.373	0.440	3
01/02/90	43	0.193	0.003	0.189	0.197	3
01/09/90	50	0.193	0.003	0.189	0.197	3
01/16/90	57	0.280	0.053	0.215	0.344	3
01/24/90	65	0.177	0.025	0.143	0.203	3
01/31/90	72	0.175	0.095	0.101	0.310	3
02/05/90	77	0.144	0.050	0.076	0.196	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	0.248	0.280	0.013	0.610	3
03/05/90	105	0.084	0.002	0.082	0.087	3
03/12/90	112	no data				0
03/19/90	119	0.083	0.009	0.076	0.095	3
03/26/90	126	0.063	0.019	0.046	0.089	3
04/03/90	134	0.191	0.067	0.099	0.253	3
04/10/90	141	0.121	0.003	0.117	0.125	3
04/16/90	147	0.121	0.003	0.117	0.125	3
04/23/90	154	0.007	0.005	0.002	0.014	3
04/30/90	161	0.076	0.014	0.064	0.096	3
05/08/90	169	0.059	0.009	0.051	0.071	3
05/14/90	175	0.025	0.002	0.022	0.028	3
05/22/90	183	0.056	0.003	0.052	0.058	3
05/25/90	186	0.031	0.008	0.020	0.037	3
05/28/90	189	no data				0
06/04/90	196	0.010	0.002	0.008	0.013	3
06/11/90	203	0.046	0.014	0.028	0.062	3
06/18/90	210	0.017	0.003	0.012	0.020	3
06/25/90	217	0.011	0.001	0.010	0.012	3
07/03/90	225	0.013	0.002	0.011	0.016	3
07/09/90	231	0.013	0.002	0.010	0.014	3
07/16/90	238	0.011	0.002	0.008	0.013	3
07/23/90	245	0.031	0.003	0.027	0.033	3
07/30/90	252	0.023	0.003	0.019	0.027	3
08/08/90	261	0.045	0.025	0.026	0.080	3
08/13/90	266	0.036	0.003	0.034	0.041	3
08/20/90	273	0.026	0.007	0.020	0.036	3
08/27/90	280	0.031	0.004	0.027	0.036	3
09/04/90	288	0.497	0.005	0.490	0.500	3
09/10/90	294	0.008	0.001	0.007	0.009	3
09/18/90	302	0.056	0.000	0.053	0.066	3
09/25/90	309	0.059	0.001	0.058	0.060	3
10/02/90	316	0.044	0.005	0.038	0.051	3
10/09/90	323	0.073	0.004	0.067	0.077	3
10/16/90	330	0.035	0.010	0.021	0.048	3
10/22/90	336	0.014	0.013	0.004	0.032	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.161	0.010	0.148	0.173	3
02/11/91	448					0
02/18/91	455	0.122	0.020	0.100	0.148	3
02/25/91	462					0
03/04/91	469	0.130	0.009	0.121	0.142	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.059	0.019	0.033	0.076	3
03/31/91	496	0.032	0.004	0.027	0.035	3
OVERALL		0.093	0.112	0.002	0.610	136
C.V.		120.31%				

NITRITE - NITROGEN INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No.
	0					
12/12/89	22	0.040	0.014	0.021	0.050	3
01/02/90	43	0.010	0.001	0.009	0.011	3
01/09/90	50	0.010	0.001	0.009	0.011	3
01/16/90	57	0.005	0.000	0.004	0.005	3
01/24/90	65	0.008	0.000	0.008	0.008	3
01/31/90	72	0.002	0.000	0.002	0.002	3
02/05/90	77	0.004	0.003	0.002	0.008	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	0.042	0.029	0.006	0.077	3
03/05/90	105	0.007	0.001	0.006	0.008	3
03/12/90	112	0.022	0.000	0.021	0.022	3
03/19/90	119	0.022	0.000	0.021	0.022	3
03/26/90	126	0.023	0.000	0.023	0.023	3
04/03/90	134	0.045	0.024	0.020	0.078	3
04/10/90	141	0.057	0.002	0.054	0.059	3
04/16/90	147	0.018	0.000	0.018	0.018	3
04/23/90	154	0.021	0.000	0.021	0.022	3
04/30/90	161	0.023	0.000	0.022	0.023	3
05/08/90	169	0.020	0.001	0.019	0.021	3
05/14/90	175	0.015	14.000	0.015	0.015	3
05/22/90	183	0.007	0.000	0.006	0.007	3
05/25/90	186	0.007	0.000	0.007	0.007	3
05/28/90	189	no data				0
06/04/90	196	0.004	0.001	0.002	0.005	3
06/11/90	203	0.004	0.000	0.004	0.004	3
06/18/90	210	0.008	0.000	0.007	0.008	3
06/25/90	217	0.100	0.000	0.100	0.100	3
07/03/90	225	0.041	0.000	0.041	0.042	3
07/09/90	231	0.027	0.000	0.027	0.027	3
07/16/90	238	0.054	0.000	0.054	0.055	3
07/23/90	245	0.040	0.000	0.040	0.041	3
07/30/90	252	0.020	0.000	0.020	0.021	3
08/08/90	261	0.007	0.000	0.007	0.008	3
08/13/90	266	0.003	0.000	0.003	0.003	3
08/20/90	273	0.005	0.000	0.005	0.005	3
08/27/90	280	0.007	0.000	0.007	0.007	3
09/04/90	288	0.004	0.000	0.004	0.004	3
09/10/90	294	0.004	0.000	0.004	0.004	3
09/18/90	302	0.002	0.000	0.002	0.002	3
09/25/90	309	0.002	0.000	0.002	0.002	3
10/02/90	316	0.069	0.000	0.068	0.069	3
10/09/90	323	0.066	0.000	0.066	0.066	3
10/16/90	330	0.051	0.000	0.051	0.051	3
10/22/90	336	0.047	0.000	0.047	0.047	3
11/05/90 to	350	project shut down				0
01/28/91	434					0
02/04/91	441	0.055	0.000	0.055	0.056	3
02/11/91	448					0
02/18/91	455	0.063	0.000	0.063	0.063	3
02/25/91	462					0
03/04/91	469	0.049	0.000	0.048	0.049	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.033	0.014	0.014	0.043	3
03/31/91	496	0.039	0.000	0.039	0.039	3
OVERALL		0.025	0.024	0.002	0.100	138
C.V.		95.96%				

NITRITE NITROGEN MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0					
12/12/89	22	0.080	0.014	0.050	0.080	3
01/02/90	43	0.050	0.000	0.049	0.050	3
01/09/90	43	0.050	0.000	0.049	0.050	3
01/16/90	57	0.020	0.001	0.019	0.021	3
01/24/90	65	0.021	0.001	0.020	0.022	3
01/31/90	72	0.008	0.001	0.008	0.009	3
02/05/90	77	0.013	0.002	0.012	0.016	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	0.017	0.012	0.002	0.031	3
03/05/90	105	0.003	0.001	0.002	0.005	3
03/12/90	112	0.012	0.001	0.010	0.013	3
03/19/90	119	0.012	0.001	0.010	0.013	3
03/26/90	126	0.016	0.000	0.010	0.023	3
04/03/90	134	0.005	0.000	0.003	0.008	3
04/10/90	141	0.041	0.005	0.033	0.045	3
04/16/90	147	0.012	0.001	0.011	0.014	3
04/23/90	154	0.007	0.001	0.006	0.009	3
04/30/90	161	0.011	0.004	0.008	0.017	3
05/08/90	169	0.029	0.003	0.026	0.034	3
05/14/90	175	0.015	0.002	0.014	0.018	3
05/22/90	183	0.021	0.000	0.021	0.021	3
05/25/90	186	0.045	0.002	0.042	0.047	3
05/28/90	189					0
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203	0.007	0.000	0.006	0.007	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.037	0.005	0.030	0.040	3
07/03/90	225	0.035	0.000	0.033	0.038	3
07/09/90	231	0.003	0.000	0.003	0.004	3
07/16/90	238	0.043	0.001	0.041	0.044	3
07/23/90	245	0.002	0.000	0.002	0.002	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261	0.024	0.001	0.022	0.025	3
08/13/90	266	0.002	0.000	0.002	0.002	3
08/20/90	273	0.023	0.000	0.023	0.024	3
08/27/90	280	0.007	0.001	0.006	0.008	3
09/04/90	288	0.020	0.000	0.018	0.022	3
09/10/90	294	0.020	0.000	0.018	0.022	3
09/18/90	302	0.003	0.000	0.002	0.003	3
09/25/90	309	0.011	0.000	0.009	0.013	3
10/02/90	316	0.012	0.001	0.011	0.013	3
10/09/90	323	0.006	0.000	0.005	0.006	3
10/16/90	330	0.005	0.000	0.004	0.005	3
10/22/90	336	0.006	0.000	0.006	0.007	3
11/05/90 to	350	project shut down				0
01/28/91	434					0
02/04/91	441	0.027	0.005	0.020	0.030	3
02/11/91	448					0
02/18/91	455	0.014	0.010	0.007	0.028	3
02/25/91	462					0
03/04/91	469	0.005	0.000	0.005	0.005	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.002	0.000	0.002	0.002	3
03/31/91	496	0.007	0.001	0.006	0.009	3
OVERALL		0.016746377	0.015	0.002	0.080	136
C.V.		0.885				

NITRITE NITROGEN EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
12/12/89	22	0.094	0.009	0.081	0.100	3
01/02/90	43	0.034	0.000	0.034	0.034	3
01/09/90	50	0.034	0.000	0.034	0.034	3
01/16/90	57	0.020	0.000	0.019	0.020	3
01/24/90	65	0.017	0.000	0.016	0.017	3
01/31/90	72	0.023	0.002	0.020	0.025	3
02/05/90	77	0.019	0.003	0.015	0.021	3
02/12/90	84	no data: system frozen				0
02/19/90	91					0
02/26/90	98	0.042	0.029	0.006	0.077	3
03/05/90	105	0.011	0.008	0.005	0.022	3
03/12/90	112	0.038	0.000	0.038	0.038	3
03/19/90	119	0.038	0.000	0.038	0.038	3
03/26/90	126	0.005	0.001	0.004	0.007	3
04/03/90	134	0.008	0.001	0.006	0.009	3
04/10/90	141	0.033	0.000	0.032	0.033	3
04/16/90	147	0.005	0.003	0.002	0.009	3
04/23/90	154	0.002	0.000	0.002	0.002	3
04/30/90	161	0.002	0.000	0.002	0.002	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.002	0.000	0.002	0.002	3
05/22/90	183	0.020	0.001	0.019	0.021	3
05/25/90	186	0.050	0.000	0.050	0.050	3
05/28/90	189	no data				0
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203	0.007	0.000	0.007	0.007	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.002	0.000	0.002	0.002	3
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231	0.004	0.000	0.004	0.004	3
07/16/90	238	0.002	0.000	0.002	0.002	3
07/23/90	245	0.002	0.000	0.002	0.002	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261	0.002	0.000	0.002	0.002	3
08/13/90	266	0.002	0.000	0.002	0.002	3
08/20/90	273	0.002	0.000	0.002	0.002	3
08/27/90	280	0.002	0.000	0.002	0.002	3
09/04/90	288	0.041	0.002	0.040	0.044	3
09/10/90	294	0.041	0.002	0.040	0.044	3
09/18/90	302	0.020	0.000	0.020	0.021	3
09/25/90	309	0.013	0.001	0.012	0.015	3
10/02/90	316	0.020	0.000	0.020	0.020	3
10/09/90	323	0.051	0.001	0.050	0.053	3
10/16/90	330	0.019	0.005	0.013	0.025	3
10/22/90	336	0.012	0.001	0.010	0.013	3
11/05/90 to	350	project shut down				0
01/28/91	434					0
02/04/91	441	0.007	0.000	0.007	0.008	3
02/11/91	448					0
02/18/91	455	0.049	0.002	0.046	0.050	3
02/25/91	462					0
03/04/91	469	0.070		0.070	0.070	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	0.073	0.002	0.070	0.075	3
03/31/91	496	0.057	0.002	0.054	0.060	3
OVERALL		0.020	0.022	0.002	0.100	138
C.V.		111.46%				

NITRATE - NITROGEN INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	29.953	0.450	29.586	30.586	3
12/12/89	22	33.126	1.362	32.079	35.050	3
01/02/90	43	21.857	0.684	20.691	22.190	3
01/09/90	50	27.330	3.565	23.197	31.897	3
01/16/90	57	23.195	1.451	21.196	24.595	3
01/22/90	63	34.896	0.490	34.296	35.496	3
01/31/90	72	0.265	0.047	0.198	0.298	3
02/05/90	77	19.662	0.474	18.992	19.998	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	21.223	0.331	20.987	21.691	3
03/06/90	106	0.359	0.053	0.312	0.434	3
03/12/90	112	no data				0
03/19/90	119	9.788	0.552	9.008	10.179	3
03/28/90	128	9.895	1.211	8.230	11.077	3
04/03/90	134	12.955	0.024	12.922	12.980	3
04/10/90	141	13.717	0.124	13.584	13.883	3
04/16/90	147	2.105	1.132	1.202	3.702	3
04/23/90	154	13.212	0.680	12.279	13.679	3
04/30/90	161	40.077	0.295	39.677	40.378	3
05/08/90	169	8.597	1.479	6.621	10.179	3
05/14/90	175	40.077	0.295	39.677	40.378	3
05/22/90	183	14.093	0.864	12.893	14.894	3
05/28/90	189	14.100	0.864	12.900	14.900	3
06/04/90	196	11.160	0.170	10.993	11.393	3
06/11/90	203	0.428	0.196	0.196	0.676	3
06/18/90	210	0.143	0.003	0.140	0.148	3
06/25/90	217	10.233	0.249	9.900	10.500	3
07/02/90	224	1.056	0.020	1.030	1.079	3
07/09/90	231	17.873	0.616	17.073	18.573	3
07/16/90	238	13.212	1.761	10.746	14.746	3
07/23/90	245	13.893	2.264	11.560	16.959	3
07/30/90	252	1.056	0.020	1.030	1.079	3
08/06/90	259	13.493	0.216	13.193	13.693	3
08/13/90	266	13.930	0.377	13.397	14.197	3
08/20/90	273	10.261	0.235	10.095	10.594	3
08/27/90	280	15.793	0.216	15.593	16.093	3
09/03/90	287	13.863	0.287	13.496	14.196	3
09/10/90	294	13.863	0.287	13.496	14.196	3
09/17/90	301	0.143	0.003	0.140	0.148	3
09/24/90	308	11.998	0.374	11.598	12.498	3
10/01/90	315	39.644	1.920	36.932	41.131	3
10/08/90	322	45.735	0.829	44.635	46.635	3
10/15/90	329	7.469	0.201	7.289	7.749	3
10/22/90	336	10.586	0.531	9.953	11.253	3
11/05/90 to	350	project shut down due to funding cut				0
01/31/91	437					0
02/04/91	441	11.612	0.249	11.345	11.945	3
02/11/91	448					0
02/18/91	455	12.670	0.047	12.637	12.737	3
02/25/91	462					0
03/04/91	469	13.751	0.294	13.451	14.151	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	18.157	0.535	17.457	18.757	3
03/31/91	496	24.726	0.309	24.461	25.161	3
OVERALL		14.806	10.896	0.140	46.635	138
C.V.		73.59%				

NITRATE - NITROGEN MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	16.694	0.922	15.943	17.993	3
12/12/89	22	11.407	0.642	10.650	12.220	3
01/02/90	43	13.317	0.170	13.150	13.551	3
01/09/90	50	11.133	0.620	10.264	11.666	3
01/16/90	57	8.947	0.047	8.880	8.981	3
01/22/90	63	6.542	0.205	6.278	6.779	3
01/31/90	72	8.392	0.221	8.084	8.592	3
02/05/90	77	7.677	1.808	5.568	9.984	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	8.288	0.351	8.019	8.782	3
03/06/90	106	2.730	0.187	2.598	2.995	3
03/12/90	112	no data				0
03/19/90	119	7.558	0.219	7.260	7.778	3
03/28/90	128	7.221	0.299	6.847	7.580	3
04/03/90	134	1.262	0.092	1.196	1.392	3
04/10/90	141	8.461	0.091	8.332	8.527	3
04/16/90	147	1.021	0.122	0.849	1.119	3
04/23/90	154	2.293	0.312	1.994	2.723	3
04/30/90	161	2.515	0.181	2.383	2.771	3
05/08/90	169	3.877	0.112	3.726	3.992	3
05/14/90	175	2.515	0.181	2.383	2.771	3
05/22/90	183	5.852	0.222	5.639	6.159	3
05/28/90	189	5.873	0.222	5.660	6.180	3
06/04/90	196	5.442	0.011	5.433	5.458	3
06/11/90	203	0.131	0.004	0.125	0.134	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	1.177	0.005	1.170	1.180	3
07/02/90	224	0.001	0.000	0.001	0.002	3
07/09/90	231	0.039	0.008	0.033	0.051	3
07/16/90	238	2.924	0.089	2.846	3.049	3
07/23/90	245	0.028	0.001	0.027	0.029	3
07/30/90	252	0.001	0.000	0.001	0.002	3
08/06/90	259	1.626	0.042	1.568	1.666	3
08/13/90	266	0.009	0.003	0.006	0.014	3
08/20/90	273	2.787	0.017	2.766	2.807	3
08/27/90	280	1.210	0.129	1.034	1.342	3
09/03/90	287	6.903	0.107	6.762	7.020	3
09/10/90	294	6.903	0.107	6.762	7.020	3
09/17/90	301	0.002	0.000	0.002	0.002	3
09/24/90	308	0.420	0.029	0.392	0.460	3
10/01/90	315	5.598	0.275	5.247	5.918	3
10/08/90	322	3.331	0.046	3.285	3.394	3
10/15/90	329	5.475	0.511	5.056	6.195	3
10/22/90	336	9.507	0.183	9.264	9.704	3
11/05/90 to	350	project shut down due to funding cut				0
01/31/91	437					0
02/04/91	441	5.373	0.751	4.350	6.130	3
02/11/91	448					0
02/18/91	455	7.326	0.657	6.462	8.053	3
02/25/91	462					0
03/04/91	469	9.048	0.073	8.945	9.105	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	9.578	0.220	9.408	9.888	3
03/31/91	496	9.173	0.121	9.081	9.344	3
OVERALL		5.000	4.047	0.001	17.993	138
C.V.		0.809				

NITRATE - NITROGEN EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	12.359	0.309	11.926	12.624	3
12/12/89	22	10.606	0.274	10.219	10.800	3
01/02/90	43	11.599	0.047	11.566	11.666	3
01/09/90	50	9.386	0.216	9.086	9.586	3
01/16/90	57	5.747	0.249	5.480	6.080	3
01/22/90	63	4.784	0.300	4.483	5.084	2
01/31/90	72	7.044	0.658	6.180	7.775	3
02/05/90	77	4.089	2.901	0.123	6.980	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	7.455	0.188	7.203	7.654	3
03/06/90	106	2.958	0.099	2.878	3.095	3
03/12/90	112	no data				0
03/19/90	119	1.329	0.047	1.262	1.362	3
03/28/90	128	0.168	0.032	0.143	0.213	3
04/03/90	134	0.130	0.010	0.118	0.142	3
04/10/90	141	0.459	0.005	0.454	0.465	3
04/16/90	147	0.004	0.001	0.003	0.006	3
04/23/90	154	0.017	0.021	0.002	0.047	3
04/30/90	161	0.003	0.001	0.002	0.004	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.003	0.001	0.002	0.004	3
05/22/90	183	2.397	0.103	2.279	2.531	3
05/28/90	189	2.417	0.103	2.300	2.550	3
06/04/90	196	2.497	0.066	2.450	2.590	3
06/11/90	203	0.367	0.018	0.343	0.386	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.002	0.000	0.002	0.002	3
07/02/90	224	0.002	0.000	0.002	0.002	3
07/09/90	231	0.003	0.000	0.002	0.003	3
07/16/90	238	0.003	0.001	0.002	0.005	3
07/23/90	245	0.007	0.004	0.001	0.011	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/06/90	259	0.002	0.000	0.002	0.002	3
08/13/90	266	0.006	0.001	0.005	0.007	3
08/20/90	273	0.002	0.000	0.002	0.002	3
08/27/90	280	0.005	0.002	0.003	0.007	3
09/03/90	287	0.424	0.010	0.412	0.437	3
09/10/90	294	0.424	0.010	0.412	0.437	3
09/17/90	301	0.002	0.000	0.002	0.002	3
09/24/90	308	0.407	0.010	0.399	0.421	3
10/01/90	315	3.010	0.086	2.910	3.120	3
10/08/90	322	4.662	0.193	4.457	4.920	3
10/15/90	329	4.505	0.200	4.275	4.762	3
10/22/90	336	5.995	0.399	5.457	6.410	3
11/05/90 to	350	project shut down due to funding cut				0
01/31/91	437					0
02/04/91	441	0.116	0.001	0.115	0.118	3
02/11/91	448					0
02/18/91	455	4.941	0.269	4.590	5.244	3
02/25/91	462					0
03/04/91	469	6.347	0.005	6.340	6.350	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	4.404	0.227	4.196	4.720	3
03/31/91	496	6.350	0.167	6.116	6.493	3
OVERALL		2.613	3.490	0.001	12.624	137
C.V.		133.55%				

TOTAL NITROGEN (mg/L) INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No
11/20/89						
12/12/89	22	35.667	0.471	35.000	36.000	3
01/02/90	43	23.000	0.000	23.000	23.000	3
01/09/90	50	23.000	0.000	23.000	23.000	3
01/16/90	57	24.333	0.471	24.000	25.000	3
01/24/90	65	71.333	0.471	71.000	72.000	3
01/31/90	72	0.333	0.005	0.330	0.340	3
02/05/90	77	19.667	0.471	19.000	20.000	3
02/12/90	84		no data; system frozen			0
02/19/90	91					0
02/26/90	98	8.533	0.189	8.400	8.800	3
03/05/90	105	0.463	0.012	0.450	0.480	3
03/12/90	112	11.000	0.000	11.000	11.000	3
03/19/90	119	11.000	0.000	11.000	11.000	3
03/26/90	126	11.000	0.000	11.000	11.000	3
04/03/90	134	13.000	0.000	13.000	13.000	3
04/10/90	141	14.000	0.000	14.000	14.000	3
04/16/90	147	3.733	0.125	3.600	3.900	3
04/23/90	154	14.000	0.000	14.000	14.000	3
04/30/90	161	41.333	0.471	41.000	42.000	3
05/07/90	168	9.967	0.386	9.600	10.500	3
05/14/90	175	14.000	14.000	14.000	14.000	3
05/22/90	183	14.667	0.471	14.000	15.000	3
05/25/90	186	12.000	0.000	12.000	12.000	3
05/28/90	189		no data			0
06/04/90	196	15.000	0.000	15.000	15.000	3
06/11/90	203	0.850	0.000	0.850	0.850	3
06/18/90	210	0.440	0.000	0.440	0.440	3
06/25/90	217	11.000	0.000	11.000	11.000	3
07/03/90	225	19.333	0.471	19.000	20.000	3
07/09/90	231	19.000	0.000	19.000	19.000	3
07/16/90	238	15.000	0.000	15.000	15.000	3
07/23/90	245	15.000	2.160	13.000	18.000	3
07/30/90	252	1.900	0.141	1.800	2.100	3
08/08/90	261	14.000	0.000	14.000	14.000	3
08/13/90	266	14.667	0.471	14.000	15.000	3
08/20/90	273	11.667	0.471	11.000	12.000	3
08/27/90	280	19.000	0.000	19.000	19.000	3
09/04/90	288	18.000	0.000	18.000	18.000	3
09/10/90	294	15.000	0.000	15.000	15.000	3
09/17/90	301	13.000	0.000	13.000	13.000	3
09/25/90	309	11.000	0.000	11.000	11.000	3
10/02/90	316	37.000	0.816	36.000	38.000	3
10/09/90	323	47.333	0.943	46.000	48.000	3
10/16/90	330	8.667	0.170	8.500	8.900	3
10/22/90	336	11.333	0.471	11.000	12.000	3
11/05/90 to	350		project shut down due to funding cut			0
01/28/91	434					0
02/04/91	441	13.667	0.471	13.000	14.000	3
02/11/91	448					0
02/18/91	455	14.000	0.000	14.000	14.000	3
02/25/91	462					0
03/04/91	469	15.000	0.000	15.000	15.000	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	20.000	0.000	20.000	20.000	3
03/31/91	496	24.933	0.094	24.800	25.000	3
OVERALL		16.899	12.831	0.330	72.000	138
C.V.		75.93%				

TOTAL NITROGEN (mg/L) MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
12/12/89	22	12.333	0.471	12.000	13.000	3
01/02/90	43	14.000	0.000	14.000	14.000	3
01/09/90	43	14.000	0.000	14.000	14.000	3
01/16/90	57	9.367	0.047	9.300	9.400	3
01/24/90	65	6.833	0.047	6.800	6.900	3
01/31/90	72	11.000	0.000	11.000	11.000	3
02/05/90	77	9.497	1.476	7.490	11.000	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	8.933	0.047	8.900	9.000	3
03/05/90	105	4.667	0.205	4.400	4.900	3
03/12/90	112	8.867	0.047	8.800	8.900	3
03/19/90	119	8.867	0.047	8.800	8.900	3
03/26/90	126	7.700	0.000	7.700	7.700	3
04/03/90	134	2.300	0.000	2.300	2.300	3
04/10/90	141	8.733	0.047	8.700	8.800	3
04/16/90	147	1.433	0.047	1.400	1.500	3
04/23/90	154	3.000	0.000	3.000	3.000	3
04/30/90	161	3.433	0.047	3.400	3.500	3
05/07/90	168	4.533	0.094	4.400	4.600	3
05/14/90	175	6.033	0.189	5.900	6.300	3
05/22/90	183	5.867	0.170	5.700	6.100	3
05/25/90	186	6.000	0.000	6.000	6.000	3
05/28/90	189	no data				0
06/04/90	196	0.607	0.005	0.600	0.610	3
06/11/90	203	0.590	0.008	0.580	0.600	3
06/18/90	210	0.430	0.000	0.430	0.430	3
06/25/90	217	1.733	0.047	1.700	1.800	3
07/03/90	225	5.900	0.000	5.900	5.900	3
07/09/90	231	0.490	0.008	0.480	0.500	3
07/16/90	238	3.367	0.125	3.200	3.500	3
07/23/90	245	0.523	0.012	0.510	0.540	3
07/30/90	252	0.513	0.029	0.480	0.550	3
08/08/90	261	2.000	0.000	2.000	2.000	3
08/13/90	266	0.443	0.005	0.440	0.450	3
08/20/90	273	3.100	0.000	3.100	3.100	3
08/27/90	280	1.633	0.047	1.600	1.700	3
09/04/90	288	0.390	0.000	0.390	0.390	3
09/10/90	294	7.400	0.000	7.400	7.400	3
09/17/90	301	0.773	0.005	0.770	0.780	3
09/25/90	309	5.900	0.000	5.900	5.900	3
10/02/90	316	6.867	0.262	6.500	7.100	3
10/09/90	323	3.567	0.047	3.500	3.600	3
10/16/90	330	5.500	0.163	5.300	5.700	3
10/22/90	336	10.000	0.000	10.000	10.000	3
11/05/90 to	350	project shut down due to funding cut				0
01/28/91	434					0
02/04/91	441	5.967	0.772	4.900	6.700	3
02/11/91	448					0
02/18/91	455	8.000	0.082	7.900	8.100	3
02/25/91	462					0
03/04/91	469	9.500	0.141	9.400	9.700	3
03/11/91	476			0.000	0.000	0
03/18/91	483			0.000	0.000	0
03/25/91	490	11.000	0.000	11.000	11.000	3
03/31/91	496	10.000	0.000	10.000	10.000	3
OVERALL		5.469347826	3.826	0.390	14.000	138
C.V.		0.700				

TOTAL NITROGEN EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
12/12/89	22	12.000	0.000	12.000	12.000	3
01/02/90	43	12.000	0.000	12.000	12.000	3
01/09/90	50	12.000	0.000	12.000	12.000	3
01/16/90	57	6.500	0.163	6.300	6.700	3
01/24/90	65	5.433	0.047	5.400	5.500	3
01/31/90	72	7.967	0.047	7.900	8.000	3
02/05/90	77	7.133	0.047	7.100	7.200	3
02/12/90	84	no data; system frozen				0
02/19/90	91					0
02/26/90	98	8.533	0.189	8.400	8.800	3
03/05/90	105	3.333	0.094	3.200	3.400	3
03/12/90	112	1.533	0.047	1.500	1.600	3
03/19/90	119	1.533	0.047	1.500	1.600	3
03/26/90	126	0.527	0.005	0.520	0.530	3
04/03/90	134	0.767	0.009	0.760	0.780	3
04/10/90	141	1.103	0.039	1.050	1.140	3
04/16/90	147	0.503	0.012	0.490	0.520	3
04/23/90	154	0.460	0.009	0.450	0.470	3
04/30/90	161	0.553	0.012	0.540	0.570	3
05/07/90	168	0.360	0.000	0.360	0.360	3
05/14/90	175	0.343	0.005	0.340	0.350	3
05/22/90	183	2.600	0.000	2.600	2.600	3
05/25/90	186	2.933	0.047	2.900	3.000	3
05/28/90	189					0
06/04/90	196	0.613	0.019	0.600	0.640	3
06/11/90	203	0.773	0.005	0.770	0.780	3
06/18/90	210	0.640	0.000	0.640	0.640	3
06/25/90	217	0.713	0.005	0.710	0.720	3
07/03/90	225	0.547	0.005	0.540	0.550	3
07/09/90	231	0.587	0.017	0.570	0.610	3
07/16/90	238	0.680	0.028	0.660	0.720	3
07/23/90	245	0.717	0.012	0.700	0.730	3
07/30/90	252	0.720	0.033	0.680	0.760	3
08/08/90	261	0.823	0.093	0.730	0.950	3
08/13/90	266	0.847	0.009	0.840	0.860	3
08/20/90	273	0.610	0.016	0.590	0.630	3
08/27/90	280	0.527	0.005	0.520	0.530	3
09/04/90	288	0.497	0.005	0.490	0.500	3
09/10/90	294	0.913	0.005	0.910	0.920	3
09/17/90	301	0.920	0.000	0.920	0.920	3
09/25/90	309	0.790	0.000	0.790	0.790	3
10/02/90	316	3.633	0.094	3.500	3.700	3
10/09/90	323	4.900	0.141	4.800	5.100	3
10/16/90	330	4.767	0.047	4.700	4.800	3
10/22/90	336	6.367	0.205	6.100	6.600	3
11/05/90 to	350	project shut down due to funding cut				0
01/28/91	434					0
02/04/91	441	0.410	0.041	0.360	0.460	3
02/11/91	448					0
02/18/91	455	5.400	0.082	5.300	5.500	3
02/25/91	462					0
03/04/91	469	6.800		6.800	6.800	3
03/11/91	476					0
03/18/91	483					0
03/25/91	490	5.067	0.094	5.000	5.200	3
03/31/91	496	7.200	0.216	7.000	7.500	3
OVERALL		2.941	3.270	0.340	12.000	138
C.V.		111.20%				

ORTHO-PHOSPHATE-P INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No.
11/20/89	0	0.002	0.000	0.002	0.003	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43	0.002	0.000	0.002	0.002	3
01/09/90	50	0.002	0.000	0.002	0.002	3
01/16/90	57	0.002	0.000	0.002	0.002	3
01/23/90	64	0.004	0.001	0.003	0.005	3
01/31/90	72	0.002	0.000	0.002	0.002	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	0.002	0.000	0.002	0.002	3
03/06/90	106	0.002	0.000	0.002	0.002	3
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126	0.002	0.000	0.002	0.002	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147	0.002	0.000	0.002	0.002	3
04/23/90	154	0.002	0.000	0.002	0.002	3
04/30/90	161	0.002	0.000	0.002	0.002	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.002	0.000	0.002	0.002	3
05/22/90	183	0.003	0.001	0.002	0.004	3
05/25/90	186	0.002	0.000	0.002	0.002	3
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203	0.002	0.000	0.002	0.002	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.002	0.000	0.002	0.002	3
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231	0.002	0.000	0.002	0.002	3
07/16/90	238	0.002	0.000	0.002	0.002	3
07/23/90	245	0.002	0.000	0.002	0.002	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261	0.002	0.000	0.002	0.002	3
08/13/90	266	0.002	0.000	0.002	0.002	3
08/20/90	273	0.002	0.000	0.002	0.002	3
08/27/90	280	0.002	0.000	0.002	0.002	3
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302	0.002	0.000	0.002	0.002	3
09/25/90	309	0.002	0.000	0.002	0.002	3
10/02/90	316	0.002	0.000	0.002	0.002	3
10/09/90	323	0.002	0.000	0.002	0.002	3
10/16/90	330	0.002	0.000	0.002	0.002	3
10/22/90	336	0.002	0.000	0.002	0.002	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455	0.002	0.000	0.002	0.002	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.002	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	0.002	0.000	0.002	0.002	3
03/31/91	496	0.003	0.000	0.003	0.003	3
OVERALL		0.002	0.000	0.002	0.005	138
C.V.		16.30%				

ORTHO-PHOSPHATE-P MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43	0.002	0.000	0.002	0.002	3
01/09/90	50	0.002	0.000	0.002	0.002	3
01/16/90	57	0.002	0.000	0.002	0.002	3
01/23/90	64	0.002	0.000	0.002	0.002	3
01/31/90	72	0.002	0.000	0.002	0.002	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	0.002	0.000	0.002	0.002	3
03/06/90	106	0.002	0.000	0.002	0.002	3
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126	0.002	0.000	0.002	0.002	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147	0.002	0.000	0.002	0.002	3
04/23/90	154	0.002	0.000	0.002	0.002	3
04/30/90	161	0.002	0.000	0.002	0.002	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.002	0.000	0.002	0.002	3
05/22/90	183	0.002	0.000	0.002	0.002	3
05/25/90	186	0.002	0.000	0.002	0.002	3
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203	0.002	0.000	0.002	0.002	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.002	0.000	0.002	0.002	3
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231	0.002	0.000	0.002	0.002	3
07/16/90	238	0.002	0.000	0.002	0.002	3
07/23/90	245	0.002	0.000	0.002	0.002	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261	0.002	0.000	0.002	0.002	3
08/13/90	266	0.002	0.000	0.002	0.002	3
08/20/90	273	0.002	0.000	0.002	0.002	3
08/27/90	280	0.002	0.000	0.002	0.002	3
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302	0.002	0.000	0.002	0.002	3
09/25/90	309	0.002	0.000	0.002	0.002	3
10/02/90	316	0.002	0.000	0.002	0.002	3
10/09/90	323	0.002	0.000	0.002	0.002	3
10/16/90	330	0.002	0.000	0.002	0.002	3
10/22/90	336	0.002	0.000	0.002	0.002	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455	0.002	0.000	0.002	0.002	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.002	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	0.002	0.000	0.002	0.002	3
03/31/91	496	0.002	0.000	0.002	0.002	3
OVERALL		0.002	0.000	0.002	0.002	138
C.V.		-				

ORTHO-PHOSPHATE-P EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43	0.002	0.000	0.002	0.002	3
01/09/90	50	0.002	0.000	0.002	0.002	3
01/16/90	57	0.002	0.000	0.002	0.002	3
01/23/90	64	0.003	0.000	0.002	0.003	3
01/31/90	72	0.002	0.000	0.002	0.002	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99	0.002	0.000	0.002	0.002	3
03/06/90	106	0.002	0.000	0.002	0.002	3
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126	0.002	0.000	0.002	0.002	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147	0.002	0.000	0.002	0.002	3
04/23/90	154	0.002	0.000	0.002	0.002	3
04/30/90	161	0.002	0.000	0.002	0.002	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.002	0.000	0.002	0.002	3
05/22/90	183	0.002	0.000	0.002	0.002	3
05/25/90	186	0.002	0.000	0.002	0.002	3
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203	0.002	0.000	0.002	0.002	3
06/18/90	210	0.002	0.000	0.002	0.002	3
06/25/90	217	0.002	0.000	0.002	0.002	3
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231	0.002	0.000	0.002	0.002	3
07/16/90	238	0.002	0.000	0.002	0.002	3
07/23/90	245	0.002	0.000	0.002	0.002	3
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261	0.002	0.000	0.002	0.002	3
08/13/90	266	0.002	0.000	0.002	0.002	3
08/20/90	273	0.002	0.000	0.002	0.002	3
08/27/90	280	0.002	0.000	0.002	0.002	3
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302	0.002	0.000	0.002	0.002	3
09/25/90	309	0.002	0.000	0.002	0.002	3
10/02/90	316	0.002	0.000	0.002	0.002	3
10/09/90	323	0.002	0.000	0.002	0.002	3
10/16/90	330	0.002	0.000	0.002	0.002	3
10/22/90	336	0.002	0.000	0.002	0.002	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455	0.002	0.000	0.002	0.002	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.002	3
03/08/91	473					0
03/18/91	483					0
03/27/91	492	0.002	0.000	0.002	0.002	3
03/31/91	496	0.002	0.000	0.002	0.002	3
OVERALL		0.002	0.000	0.002	0.003	138
C.V.		5.93%				

TOTAL DISSOLVED PHOSPHORUS INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No.
11/20/89	0	0.021	0.001	0.020	0.022	3
12/12/89	22	0.002	0.000	0.002	0.003	3
01/02/90	43	0.006	0.000	0.006	0.007	3
01/09/90	50	0.009	0.001	0.008	0.010	3
01/16/90	57	0.002	0.000	0.002	0.003	3
01/23/90	64	0.002	0.000	0.002	0.002	3
01/31/90	72	0.003	0.001	0.002	0.004	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106	0.003	0.000	0.003	0.004	3
03/12/90	112					0
03/19/90	119	0.003	0.000	0.003	0.004	3
03/26/90	126	0.003	0.000	0.003	0.003	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.004	0.000	0.004	0.004	3
04/16/90	147	0.003	0.000	0.003	0.003	3
04/23/90	154	0.003	0.000	0.003	0.004	3
04/30/90	161	0.003	0.000	0.003	0.004	3
05/08/90	169	0.002	0.000	0.002	0.003	3
05/14/90	175	0.003	0.000	0.003	0.004	3
05/22/90	183	0.008	0.006	0.003	0.017	3
05/25/90	186	0.019	0.011	0.005	0.031	3
06/04/90	196	0.006	0.004	0.002	0.009	2
06/11/90	203	0.018	0.018	0.004	0.043	3
06/18/90	210	0.017	0.014	0.007	0.037	3
06/25/90	217	0.008	0.003	0.005	0.012	3
07/02/90	224	0.006	0.000	0.006	0.006	3
07/09/90	231	0.002	0.000	0.002	0.002	3
07/16/90	238	0.003	0.000	0.002	0.003	3
07/23/90	245	0.003	0.000	0.003	0.004	3
07/30/90	252	0.004	0.000	0.004	0.004	3
08/08/90	261					0
08/13/90	266	0.006	0.000	0.005	0.006	3
08/20/90	273	0.007	0.001	0.006	0.008	3
08/27/90	280	0.003	0.000	0.003	0.004	3
09/04/90	288	0.004	0.000	0.004	0.004	3
09/10/90	294	0.004	0.000	0.004	0.004	3
09/18/90	302	0.004	0.000	0.004	0.005	3
09/25/90	309	0.004	0.000	0.004	0.004	3
10/02/90	316	0.004	0.000	0.004	0.005	3
10/09/90	323	0.004	0.000	0.003	0.004	3
10/16/90	330	0.005	0.000	0.005	0.005	3
10/22/90	336	0.005	0.001	0.004	0.006	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.003	0.000	0.002	0.003	3
02/11/91	448					0
02/18/91	455	0.005	0.000	0.004	0.005	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.003	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	0.002	0.000	0.002	0.002	3
03/31/91	496	0.005	0.001	0.003	0.006	3
OVERALL		0.005	0.004	0.002	0.043	45
C.V.		68.21%				

TOTAL DISSOLVED PHOSPHORUS MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.005	0.000	0.004	0.005	3
12/12/89	22	0.003	0.000	0.002	0.003	3
01/02/90	43	0.004	0.000	0.004	0.004	3
01/09/90	50	0.004	0.000	0.004	0.004	2
01/16/90	57	0.002	0.000	0.002	0.002	3
01/23/90	64	0.002	0.000	0.002	0.002	3
01/31/90	72	0.002	0.000	0.002	0.003	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106	0.003	0.000	0.002	0.003	3
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126	0.002	0.000	0.002	0.003	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147	0.003	0.000	0.003	0.003	2
04/23/90	154	0.002	0.000	0.002	0.002	3
04/30/90	161	0.004	0.000	0.004	0.004	3
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175	0.004	0.000	0.004	0.004	3
05/22/90	183	0.014	0.011	0.005	0.030	3
05/25/90	186	0.007	0.005	0.003	0.014	3
06/04/90	196	0.004	0.000	0.004	0.004	1
06/11/90	203	0.017	0.017	0.005	0.042	3
06/18/90	210	0.007	0.000	0.004	0.013	3
06/25/90	217	0.017	0.018	0.004	0.043	3
07/02/90	224	0.005	0.000	0.005	0.005	3
07/09/90	231	0.028	0.023	0.011	0.061	3
07/16/90	238	0.006	0.000	0.006	0.006	3
07/23/90	245	0.004	0.000	0.004	0.004	3
07/30/90	252	0.005	0.000	0.005	0.005	3
08/08/90	261					0
08/13/90	266	0.006	0.000	0.006	0.006	3
08/20/90	273	0.004	0.000	0.004	0.005	3
08/27/90	280	0.004	0.000	0.004	0.004	3
09/04/90	288	0.004	0.000	0.004	0.004	2
09/10/90	294	0.003	0.000	0.003	0.004	3
09/18/90	302	0.003	0.000	0.003	0.004	3
09/25/90	309	0.003	0.000	0.003	0.004	3
10/02/90	316	0.006	0.000	0.006	0.006	3
10/09/90	323	0.005	0.000	0.005	0.005	3
10/16/90	330	0.004	0.000	0.004	0.004	3
10/22/90	336	0.004	0.000	0.004	0.005	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455	0.003	0.001	0.002	0.004	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.002	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	0.002	0.000	0.002	0.002	3
03/31/91	496	0.005	0.000	0.004	0.005	3
OVERALL		0.005	0.005	0.002	0.061	64
C.V.		1.025				

TOTAL DISSOLVED PHOSPHORUS EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.004	0.000	0.004	0.004	3
12/12/89	22	0.003	0.000	0.003	0.003	3
01/02/90	43	0.004	0.000	0.003	0.004	3
01/09/90	50	0.005	0.000	0.004	0.005	3
01/16/90	57	0.003	0.000	0.002	0.003	3
01/23/90	64	0.002	0.000	0.002	0.002	3
01/31/90	72	0.003	0.000	0.002	0.003	3
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106	0.003	0.000	0.003	0.003	3
03/12/90	112	no data				0
03/19/90	119	0.004	0.000	0.004	0.005	3
03/26/90	126	0.004	0.000	0.004	0.005	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.004	0.000	0.004	0.004	3
04/16/90	147	0.005	0.000	0.005	0.005	3
04/23/90	154	0.004	0.000	0.004	0.005	3
04/30/90	161	0.003	0.001	0.002	0.004	3
05/08/90	169	0.002	0.000	0.002	0.003	3
05/14/90	175	0.003	0.001	0.002	0.004	3
05/22/90	183	0.014	0.007	0.005	0.020	3
05/25/90	186	0.021	0.013	0.011	0.040	3
06/04/90	196					0
06/11/90	203	0.019	0.018	0.005	0.045	3
06/18/90	210	0.041	0.000	0.008	0.066	3
06/25/90	217	0.038	0.000	0.009	0.064	3
07/02/90	224	0.005	0.000	0.004	0.005	3
07/09/90	231	0.060	0.048	0.011	0.125	3
07/16/90	238	0.005	0.000	0.005	0.006	3
07/23/90	245	0.006	0.000	0.006	0.007	3
07/30/90	252	0.006	0.000	0.005	0.006	3
08/08/90	261					0
08/13/90	266	0.013	0.000	0.013	0.014	3
08/20/90	273	0.006	0.000	0.005	0.006	3
08/27/90	280	0.005	0.001	0.004	0.006	3
09/04/90	288	0.004	0.000	0.004	0.005	3
09/10/90	294	0.004	0.000	0.004	0.005	3
09/18/90	302	0.004	0.000	0.004	0.005	3
09/25/90	309	0.004	0.000	0.004	0.004	3
10/02/90	316	0.007	0.000	0.006	0.007	3
10/09/90	323	0.005	0.000	0.004	0.005	3
10/16/90	330	0.004	0.000	0.004	0.005	3
10/22/90	336	0.004	0.000	0.003	0.004	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455	0.003	0.000	0.002	0.003	3
02/25/91	462					0
03/04/91	469	0.002	0.000	0.002	0.003	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	0.003	0.000	0.002	0.003	3
03/31/91	496	0.006	0.001	0.005	0.007	3
OVERALL		0.008	0.008	0.002	0.125	64
C.V.		96.62%				

TOTAL PHOSPHORUS INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	No.
11/20/89	0	0.043	0.002	0.041	0.046	3
12/12/89	22	0.005	0.001	0.004	0.006	3
01/02/90	43	0.035	0.002	0.032	0.036	3
01/09/90	50	0.012	0.001	0.011	0.013	3
01/16/90	57	0.005	0.000	0.005	0.006	3
01/23/90	64	0.015	0.000	0.014	0.015	3
01/31/90	72	0.003	0.001	0.002	0.004	3
02/05/90	77	0.008	0.001	0.007	0.010	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99			0.000	0.000	0
03/06/90	106	0.006	0.000	0.005	0.006	3
03/12/90	112		no data			0
03/19/90	119	0.008	0.000	0.007	0.008	3
03/26/90	126	0.008	0.000	0.008	0.008	3
04/03/90	134	0.003	0.000	0.003	0.004	3
04/10/90	141	0.004	0.000	0.004	0.004	3
04/16/90	147	0.003	0.000	0.003	0.004	3
04/23/90	154	0.005	0.000	0.005	0.005	3
04/30/90	161	0.003	0.000	0.003	0.004	3
05/08/90	169	0.006	0.000	0.005	0.006	3
05/14/90	175	0.003	0.000	0.003	0.004	3
05/22/90	183	0.008	0.000	0.007	0.008	3
05/25/90	186	0.007	0.000	0.007	0.008	3
06/04/90	196	0.006	0.000	0.005	0.006	3
06/11/90	203	0.009	0.001	0.008	0.010	3
06/18/90	210	0.006	0.000	0.006	0.006	3
06/25/90	217	0.005	0.000	0.005	0.006	3
07/02/90	224	0.006	0.000	0.006	0.006	3
07/09/90	231	0.007	0.000	0.007	0.007	3
07/16/90	238	0.006	0.000	0.006	0.006	3
07/23/90	245	0.005	0.000	0.004	0.005	3
07/30/90	252	0.007	0.000	0.006	0.007	3
08/08/90	261	0.008	0.000	0.007	0.008	3
08/13/90	266	0.006	0.000	0.006	0.007	3
08/20/90	273	0.017	0.000	0.017	0.018	3
08/27/90	280	0.008	0.000	0.007	0.008	3
09/04/90	288	0.007	0.000	0.007	0.008	3
09/10/90	294	0.007	0.000	0.007	0.008	3
09/18/90	302	0.008	0.000	0.008	0.008	3
09/25/90	309	0.007	0.001	0.006	0.008	3
10/02/90	316	0.009	0.000	0.008	0.009	3
10/09/90	323	0.009	0.000	0.008	0.009	3
10/16/90	330	0.010	0.000	0.010	0.010	3
10/22/90	336	0.007	0.000	0.007	0.008	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.011	0.000	0.011	0.011	3
02/11/91	448					0
02/18/91	455	0.010	0.000	0.009	0.010	3
02/25/91	462					0
03/04/91	469	0.004	0.000	0.004	0.004	3
03/08/91	473			0		0
03/18/91	483					0
03/25/91	490	0.004	0.000	0.004	0.004	3
03/31/91	496	0.007	0.000	0.006	0.007	3
OVERALL		0.009	0.007	0.002	0.046	135
C.V.		84.62%				

TOTAL PHOSPHORUS MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
11/20/89	0	0.012	0.001	0.011	0.013	3
12/12/89	22	0.004	0.000	0.004	0.005	3
01/02/90	43	0.032	0.004	0.027	0.035	3
01/09/90	50	0.004	0.000	0.004	0.004	3
01/16/90	57	0.002	0.000	0.002	0.003	3
01/23/90	64	0.006	0.001	0.005	0.007	3
01/31/90	72	0.021	0.003	0.018	0.025	3
02/05/90	77	0.006	0.000	0.006	0.006	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106	0.027	0.002	0.025	0.029	3
03/12/90	112	no data				0
03/19/90	119	0.003	0.000	0.003	0.003	3
03/26/90	126	0.003	0.000	0.003	0.004	3
04/03/90	134	0.002	0.000	0.002	0.002	3
04/10/90	141	0.004	0.000	0.004	0.004	3
04/16/90	147	0.003	0.000	0.003	0.003	3
04/23/90	154	0.004	0.000	0.004	0.005	3
04/30/90	161	0.004	0.000	0.004	0.004	3
05/08/90	169	0.008	0.000	0.007	0.008	3
05/14/90	175	0.004	0.000	0.004	0.004	3
05/22/90	183	0.003	0.000	0.003	0.004	3
05/25/90	186	0.011	0.000	0.010	0.011	3
06/04/90	196	0.010	0.000	0.010	0.010	2
06/11/90	203	0.004	0.000	0.003	0.004	3
06/18/90	210	0.005	0.000	0.005	0.006	3
06/25/90	217	0.006	0.000	0.006	0.006	3
07/02/90	224	0.008	0.000	0.007	0.008	3
07/09/90	231	0.006	0.000	0.005	0.006	3
07/16/90	238	0.009	0.000	0.009	0.010	3
07/23/90	245	0.008	0.001	0.007	0.008	2
07/30/90	252	0.009	0.000	0.009	0.010	3
08/08/90	261	0.007	0.000	0.007	0.008	3
08/13/90	266	0.007	0.000	0.006	0.007	3
08/20/90	273	0.010	0.000	0.009	0.010	3
08/27/90	280	0.005	0.000	0.005	0.005	3
09/04/90	288	0.006	0.000	0.005	0.006	3
09/10/90	294	0.006	0.000	0.005	0.006	3
09/18/90	302	0.006	0.000	0.006	0.006	3
09/25/90	309	0.004	0.000	0.003	0.004	3
10/02/90	316	0.012	0.002	0.010	0.014	3
10/09/90	323	0.007	0.000	0.007	0.007	3
10/16/90	330	0.005	0.001	0.004	0.006	3
10/22/90	336	0.005	0.000	0.005	0.006	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.004	0.000	0.003	0.004	3
02/11/91	448					0
02/18/91	455	0.005	0.000	0.005	0.005	3
02/25/91	462					0
03/04/91	469	0.003	#NUM!	0.003	0.003	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	0.003	0.000	0.003	0.004	3
03/31/91	496	0.005	0.000	0.005	0.006	3
OVERALL		0.007	0.006	0.002	0.035	133
C.V.		0.841				

TOTAL PHOSPORUS EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	No.
11/20/89	0	0.008	0.000	0.008	0.009	3
12/12/89	22	0.003	0.000	0.003	0.004	3
01/02/90	43	0.023	0.003	0.019	0.027	3
01/09/90	50	0.005	0.000	0.005	0.005	3
01/16/90	57	0.006	0.000	0.005	0.006	3
01/23/90	64	0.004	0.000	0.004	0.004	3
01/31/90	72	0.010	0.001	0.008	0.011	3
02/05/90	77	0.004	0.000	0.004	0.005	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106	0.011	0.000	0.011	0.012	3
03/12/90	112	no data				0
03/19/90	119	0.010	0.001	0.009	0.011	3
03/26/90	126	0.010	0.001	0.009	0.011	3
04/03/90	134	0.008	0.000	0.007	0.008	3
04/10/90	141	0.007	0.001	0.006	0.008	3
04/16/90	147	0.011	0.000	0.010	0.011	3
04/23/90	154	0.008	0.000	0.008	0.008	3
04/30/90	161	0.007	0.000	0.007	0.007	3
05/08/90	169	0.005	0.000	0.004	0.005	3
05/14/90	175	0.007	0.000	0.007	0.007	3
05/22/90	183	0.006	0.000	0.006	0.006	3
05/25/90	186	0.012	0.000	0.012	0.013	3
06/04/90	196	0.009	0.000	0.009	0.009	3
06/11/90	203	0.006	0.000	0.005	0.006	3
06/18/90	210	0.010	0.000	0.009	0.010	3
06/25/90	217	0.011	0.000	0.011	0.012	3
07/02/90	224	0.009	0.000	0.009	0.010	3
07/09/90	231	0.011	0.000	0.010	0.011	3
07/16/90	238	0.011	0.000	0.011	0.012	3
07/23/90	245	0.007	0.004	0.001	0.011	3
07/30/90	252	0.013	0.000	0.013	0.013	3
08/08/90	261	0.016	0.000	0.015	0.016	3
08/13/90	266	0.019	0.001	0.018	0.020	3
08/20/90	273	0.013	0.000	0.013	0.013	3
08/27/90	280	0.009	0.000	0.008	0.009	3
09/04/90	288	0.007	0.000	0.007	0.007	3
09/10/90	294	0.007	0.000	0.007	0.007	3
09/18/90	302	0.008	0.000	0.008	0.008	3
09/25/90	309	0.007	0.000	0.007	0.007	3
10/02/90	316	0.013	0.001	0.012	0.014	3
10/09/90	323	0.006	0.001	0.005	0.007	3
10/16/90	330	0.005	0.000	0.005	0.005	3
10/22/90	336	0.005	0.001	0.004	0.006	3
11/05/90 to	350					0
01/28/91	434					0
02/04/91	441	0.010	0.000	0.009	0.010	3
02/11/91	448					0
02/18/91	455	0.006	0.000	0.005	0.006	3
02/25/91	462					0
03/04/91	469	0.005	0.000	0.004	0.005	3
03/08/91	473					0
03/18/91	483					0
03/25/91	490	0.006	0.000	0.006	0.006	3
03/31/91	496	0.009	0.001	0.007	0.010	3
OVERALL		0.009	0.004	0.001	0.027	135
C.V.		45.98%				

PARAMETER: Total aluminum INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	1.257	0.039	1.220	1.310	3
12/12/89	22	0.208	0.020	0.180	0.222	3
01/02/90	43					0
01/09/90	50	0.537	0.042	0.480	0.580	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.370	0.042	0.340	0.430	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.173	0.009	0.160	0.180	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.078	0.018	0.053	0.095	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.053	0.003	0.051	0.057	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.035	0.010	0.025	0.048	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.047	0.015	0.033	0.068	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.042	0.006	0.033	0.048	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.153	0.009	0.142	0.165	3
09/10/90	294	0.153	0.009	0.142	0.165	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.143	0.011	0.129	0.156	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	3.230	1.160	1.770	4.660	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.126	0.001	0.124	0.127	3
OVERALL		0.487	0.915	0.025	4.660	39
C.V.		188.10%				

PARAMETER: Total aluminum MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.061	0.008	0.055	0.072	3
12/12/89	22	0.046	0.013	0.033	0.064	3
01/02/90	43					0
01/09/90	50	0.030	0.018	0.010	0.053	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.072	0.013	0.054	0.083	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.038	0.012	0.027	0.055	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.027	0.001	0.026	0.028	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.028	0.017	0.015	0.053	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.050	0.004	0.045	0.056	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.028	0.005	0.021	0.032	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.032	0.002	0.029	0.035	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.038	0.008	0.031	0.049	3
09/10/90	294	0.038	0.008	0.031	0.049	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.051	0.003	0.049	0.056	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.110	0.013	0.092	0.121	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.020	0.005	0.016	0.028	3
OVERALL		0.047	0.025	0.010	0.121	39
C.V.		0.531				

PARAMETER: Total aluminum EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.074	0.026	0.054	0.110	3
12/12/89	22	0.039	0.018	0.015	0.059	3
01/02/90	43					0
01/09/90	50	0.035	0.020	0.018	0.064	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.036	0.004	0.031	0.040	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.047	0.006	0.040	0.055	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.038	0.011	0.023	0.051	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.026	0.000	0.021	0.030	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.063	0.006	0.057	0.072	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.029	0.000	0.027	0.033	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.031	0.000	0.027	0.037	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.049	0.003	0.045	0.051	3
09/10/90	294	0.049	0.003	0.045	0.051	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.057	0.010	0.045	0.069	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.023	0.010	0.010	0.033	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.011	0.002	0.009	0.014	3
OVERALL		0.042	0.019	0.010	0.110	39
C.V.		44.94%				

PARAMETER: Total Copper INFLUENT units: mg/l

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.010	0.000	0.009	0.010	3
12/12/89	22	0.003	0.000	0.003	0.004	3
01/02/90	43				0.000	0
01/09/90	50	0.002	0.000	0.002	0.002	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.003	0.000	0.003	0.003	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.003	0.000	0.002	0.003	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.004	0.000	0.004	0.005	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.007	0.004	0.003	0.013	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.001	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.003	0.000	0.003	0.003	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.003	0.001	0.002	0.004	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.004	0.000	0.003	0.004	3
09/10/90	294	0.004	0.000	0.003	0.004	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.002	0.000	0.002	0.003	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.006	0.002	0.005	0.009	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.005	0.001	0.005	0.006	3
OVERALL		0.004	0.003	0.001	0.013	39
C.V.		69.55%				

PARAMETER: Total Copper MIDPOINT units: mg/l

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.003	3
12/12/89	22	0.003	0.000	0.003	0.004	3
01/02/90	43					0
01/09/90	50	0.002	0.001	0.001	0.004	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.001	0.000	0.001	0.002	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.004	0.000	0.004	0.004	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.003	0.000	0.003	0.003	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.002	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.001	0.001	0.001	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.003	0.001	0.002	0.004	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.002	0.000	0.002	0.002	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.004	0.000	0.004	0.004	3
OVERALL		0.002	0.001	0.001	0.004	39
C.V.		0.387				

PARAMETER: Total Copper EFFLUENT units: mg/l

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.001	0.000	0.001	0.001	3
12/12/89	22	0.003	0.000	0.003	0.004	3
01/02/90	43					0
01/09/90	50	0.004	0.004	0.002	0.010	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.002	0.000	0.002	0.003	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.003	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.003	0.000	0.003	0.004	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.003	0.000	0.002	0.003	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.001	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.003	0.000	0.002	0.003	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.003	0.000	0.002	0.003	3
09/10/90	294	0.003	0.000	0.002	0.003	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.001	0.000	0.001	0.001	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.002	0.002	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.003	0.000	0.003	0.004	3
OVERALL		0.002	0.002	0.001	0.010	39
C.V.		64.89%				

PARAMETER: Total Iron INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	1.737	0.065	1.660	1.820	3
12/12/89	22	0.615	0.089	0.551	0.741	3
01/02/90	43					0
01/09/90	50	0.705	0.028	0.665	0.725	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.490	0.024	0.471	0.523	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	1.353	0.337	1.110	1.830	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.430	0.010	0.423	0.444	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.537	0.023	0.507	0.562	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.367	0.099	0.227	0.445	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.462	0.067	0.387	0.538	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.348	0.001	0.346	0.349	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.383	0.012	0.367	0.395	3
09/10/90	294	0.383	0.012	0.367	0.395	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.338	0.011	0.326	0.353	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	2.343	0.734	1.570	3.330	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.467	0.015	0.455	0.489	3
OVERALL		0.779	0.649	0.227	3.330	39
C.V.		83.26%				

PARAMETER: Total Iron MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.064	0.003	0.061	0.069	3
12/12/89	22	0.061	0.009	0.048	0.068	3
01/02/90	43					0
01/09/90	50	0.036	0.005	0.033	0.043	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.291	0.050	0.220	0.326	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.193	0.049	0.145	0.261	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.069	0.028	0.033	0.100	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.056	0.007	0.048	0.064	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.471	0.013	0.459	0.489	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.370	0.015	0.357	0.391	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	1.012	0.096	0.908	1.140	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.192	0.052	0.118	0.229	3
09/10/90	294	0.192	0.052	0.118	0.229	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.083	0.012	0.071	0.100	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.143	0.002	0.142	0.146	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.036	0.012	0.020	0.048	3
OVERALL		0.234	0.262	0.033	1.140	39
C.V.		1.120				

PARAMETER: Total Iron EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.084	0.003	0.080	0.088	3
12/12/89	22	0.128	0.007	0.123	0.138	3
01/02/90	43					0
01/09/90	50	0.129	0.010	0.118	0.142	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.237	0.024	0.217	0.270	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/08/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.512	0.023	0.479	0.530	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.293	0.029	0.261	0.332	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.458	0.000	0.444	0.475	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.432	0.058	0.359	0.501	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.610	0.000	0.555	0.666	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.335	0.000	0.332	0.338	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.123	0.005	0.119	0.130	3
09/10/90	294	0.123	0.005	0.119	0.130	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.079	0.013	0.066	0.096	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.287	0.004	0.281	0.291	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.078	0.007	0.069	0.085	3
OVERALL		0.285	0.171	0.066	0.666	39
C.V.		59.94%				

PARAMETER: Total Potassium INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	81.333	0.471	81.000	82.000	3
12/12/89	22	93.000	0.816	92.000	94.000	3
01/02/90	43					0
01/09/90	50	67.000	0.816	66.000	68.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	54.667	1.247	53.000	56.000	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	23.667	0.471	23.000	24.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	36.667	0.471	36.000	37.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	26.333	0.471	26.000	27.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	41.000	0.000	41.000	41.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	50.000	0.000	50.000	50.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	26.333	0.471	26.000	27.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	50.333	0.471	50.000	51.000	3
09/10/90	294	50.333	0.471	50.000	51.000	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	109.667		1088.000	111.000	0
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	33.333	1.886	32.000	36.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	62.333	0.471	62.000	63.000	3
OVERALL		53.333	26.190	23.000	111.000	39
C.V.		49.11%				

PARAMETER: Total Potassium MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	62.000	0.816	61.000	63.000	3
12/12/89	22	53.333	0.471	53.000	54.000	3
01/02/90	43					0
01/09/90	50	35.667	0.471	35.000	36.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	32.667	0.471	32.000	33.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	18.667	0.471	18.000	19.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	31.333	0.471	31.000	32.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	27.333	0.943	26.000	28.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	22.333	0.471	22.000	23.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	31.333	0.943	30.000	32.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	18.667	0.471	18.000	19.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	16.000	0.000	16.000	16.000	3
09/10/90	294	16.000	0.000	16.000	16.000	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	34.000		33.000	35.000	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	14.333	0.471	14.000	15.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	28.667	0.471	28.000	29.000	3
OVERALL		30.590	13.564	14.000	63.000	39
C.V.		0.443				

PARAMETER: Total Potassium EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	53.333	0.471	53.000	54.000	3
12/12/89	22	56.667	0.943	56.000	58.000	3
01/02/90	43					0
01/09/90	50	33.333	0.471	33.000	34.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	28.667	0.471	28.000	29.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	15.000	0.000	15.000	15.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	24.667	0.471	24.000	25.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	24.000	0.000	23.000	25.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	24.000	0.000	24.000	24.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	21.000	0.000	20.000	22.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	4.000	0.000	4.000	4.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	24.667	0.471	24.000	25.000	3
09/10/90	294	24.667	0.471	24.000	25.000	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	36.000		36.000	36.000	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	2.667	0.471	2.000	3.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	25.333	0.471	25.000	26.000	3
OVERALL		26.769	15.268	2.000	58.000	39
C.V.		57.03%				

PARAMETER: Total Manganese INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.222	0.001	0.220	0.223	3
12/12/89	22	0.162	0.008	0.155	0.173	3
01/02/90	43					0
01/08/90	50	0.099	0.001	0.098	0.100	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.051	0.001	0.050	0.052	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.302	0.005	0.295	0.308	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.165	0.002	0.162	0.168	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.106	0.003	0.102	0.109	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.053	0.021	0.024	0.068	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.078	0.015	0.067	0.099	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.052	0.003	0.048	0.054	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.043	0.004	0.039	0.048	3
09/10/90	294	0.043	0.004	0.039	0.048	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.025	0.001	0.024	0.026	3
10/09/90 to	323			0.000	0.000	0
01/28/91	434			0.000	0.000	0
02/04/91	441	0.380	0.022	0.359	0.411	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.333	0.002	0.331	0.335	3
OVERALL		0.134	0.106	0.024	0.411	39
C.V.		79.03%				

PARAMETER: Total Manganese MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.045	0.000	0.044	0.045	3
12/12/89	22	0.028	0.002	0.026	0.031	3
01/02/90	43					0
01/09/90	50	0.013	0.001	0.012	0.014	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.111	0.004	0.108	0.116	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.040	0.012	0.028	0.056	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.018	0.001	0.017	0.019	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.034	0.001	0.033	0.035	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.231	0.002	0.228	0.234	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.262	0.004	0.257	0.265	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.498	0.002	0.496	0.501	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.066	0.000	0.066	0.067	3
09/10/90	294	0.066	0.000	0.066	0.067	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.026	0.000	0.026	0.026	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.103	0.005	0.100	0.110	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.008	0.000	0.008	0.009	3
OVERALL		0.114	0.135	0.012	0.501	39
C.V.		1.169				

PARAMETER: Total Manganese EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.089	0.001	0.087	0.090	3
12/12/89	22	0.178	0.002	0.176	0.180	3
01/02/90	43					0
01/09/90	50	0.107	0.001	0.106	0.108	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.348	0.003	0.346	0.352	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.466	0.008	0.456	0.476	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.188	0.002	0.185	0.190	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.799	0.000	0.789	0.817	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.200	0.005	0.193	0.206	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.897	0.000	0.886	0.910	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.415	0.000	0.412	0.417	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.095	0.001	0.093	0.096	3
09/10/90	294	0.095	0.001	0.093	0.096	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.086	0.001	0.085	0.087	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.251	0.003	0.246	0.253	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.567	0.009	0.560	0.580	3
OVERALL		0.317	0.257	0.085	0.910	39
C.V.		80.98%				

PARAMETER: Total zinc INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.010	0.001	0.008	0.011	3
12/12/89	22	0.008	0.001	0.007	0.009	3
01/02/90	43					0
01/09/90	50	0.009	0.002	0.007	0.011	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.008	0.002	0.005	0.011	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.011	0.007	0.005	0.020	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.007	0.001	0.006	0.009	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.006	0.008	0.002	0.015	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.005	0.004	0.002	0.010	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.004	0.003	0.002	0.009	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.003	3
09/10/90	294	0.002	0.000	0.002	0.003	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.005	0.002	0.002	0.007	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.011	0.002	0.009	0.014	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.011	0.001	0.010	0.012	3
OVERALL		0.007	0.004	0.002	0.020	39
C.V.		62.10%				

PARAMETER: Total zinc MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.004	0.002	0.002	0.007	3
01/02/90	43					0
01/09/90	50	0.005	0.005	0.002	0.012	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.003	0.001	0.002	0.004	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.003	0.001	0.002	0.004	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.005	0.003	0.002	0.009	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.003	0.001	0.002	0.004	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.003	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.004	0.001	0.002	0.005	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.012	0.003	0.010	0.016	3
02/11/31	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.008	0.005	0.003	0.015	3
OVERALL		0.004	0.003	0.002	0.016	39
C.V.		0.883				

PARAMETER: Total zinc EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43					0
01/09/90	50	0.006	0.004	0.002	0.011	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.003	0.000	0.003	0.004	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.003	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.003	0.000	0.002	0.003	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.007	0.007	0.002	0.016	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.008	0.000	0.002	0.019	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.003	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.004	0.002	0.002	0.007	3
09/10/90	294	0.004	0.002	0.002	0.007	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.012	0.004	0.008	0.018	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.015	0.004	0.010	0.020	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.007	0.001	0.005	0.008	3
OVERALL		0.005	0.005	0.002	0.020	39
C.V.		103.28%				

PARAMETER: Diss. Aluminum INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.007	0.003	0.005	0.011	3
12/12/89	22	0.028	0.003	0.024	0.032	3
01/02/90	43					0
01/09/90	50	0.068	0.028	0.045	0.107	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77					0
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.006	0.001	0.005	0.008	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.008	0.001	0.006	0.009	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.011	0.001	0.009	0.012	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.028	0.025	0.010	0.064	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.011	0.002	0.009	0.013	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.014	0.004	0.011	0.019	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.021	0.001	0.020	0.022	3
09/10/90	294	0.021	0.001	0.020	0.022	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.014	0.001	0.013	0.016	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.012	0.002	0.009	0.013	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.010	0.001	0.008	0.011	3
OVERALL		0.019	0.020	0.005	0.107	36
C.V.		104.32%				

PARAMETER: Diss. Aluminum MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.003	3
12/12/89	22	0.013	0.001	0.012	0.014	3
01/02/90	43					0
01/09/90	50	0.013	0.005	0.008	0.020	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77					0
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.008	0.000	0.008	0.008	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.011	0.002	0.009	0.013	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.009	0.001	0.008	0.010	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.012	0.002	0.010	0.015	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.013	0.004	0.008	0.018	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.016	0.003	0.013	0.020	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.017	0.002	0.014	0.019	3
09/10/90	294	0.017	0.002	0.014	0.019	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.009	0.000	0.009	0.010	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.010	0.000	0.010	0.010	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.010	0.001	0.008	0.011	3
OVERALL		0.011	0.004	0.002	0.020	36
C.V.		0.394				

PARAMETER: Diss. Aluminum EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.011	0.000	0.010	0.011	3
01/02/90	43					0
01/09/90	50	0.007	0.001	0.006	0.008	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77					0
02/12/90	84	no data; winter freeze-up				
02/19/90	91					
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				
03/19/90	119	0.013	0.000	0.013	0.013	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.012	0.002	0.009	0.015	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.016	0.000	0.015	0.018	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.009	0.001	0.008	0.010	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.021	0.000	0.016	0.027	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.014	0.000	0.012	0.015	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.017	0.003	0.012	0.020	3
09/10/90	294	0.017	0.003	0.012	0.020	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.009	0.002	0.007	0.011	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.007	0.000	0.007	0.008	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.006	0.002	0.004	0.009	3
OVERALL		0.012	0.005	0.002	0.027	36
C.V.		45.97%				

PARAMETER: Diss. Copper INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.003	3
12/12/89	22	0.002	0.000	0.001	0.002	3
01/02/90	43					0
01/09/90	50	0.001	0.000	0.001	0.001	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.001	0.000	0.001	0.001	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.003	0.000	0.003	0.003	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.005	0.002	0.003	0.008	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.001	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.003	0.000	0.003	0.003	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.003	0.001	0.002	0.004	3
09/10/90	294	0.003	0.001	0.002	0.004	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.004	0.000	0.003	0.004	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.003	0.000	0.002	0.003	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.002	0.000	0.002	0.002	3
OVERALL		0.002	0.001	0.001	0.008	39
C.V.		53.46%				

PARAMETER: Diss. Copper MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.001	0.000	0.001	0.001	3
12/12/89	22	0.003	0.001	0.002	0.003	3
01/02/90	43					0
01/09/90	50	0.001	0.000	0.001	0.001	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.001	0.000	0.001	0.001	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.001	0.000	0.001	0.002	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.012	0.013	0.003	0.030	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.003	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.001	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.001	0.000	0.001	0.001	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.002	0.001	0.001	0.003	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.002	0.000	0.001	0.002	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.001	0.000	0.001	0.001	3
OVERALL		0.002	0.005	0.001	0.030	39
C.V.		1.904				

PARAMETER: Diss. Copper EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.001	0.000	0.001	0.001	3
12/12/89	22	0.003	0.000	0.003	0.004	3
01/02/90	43					0
01/09/90	50	0.001	0.000	0.001	0.001	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.001	0.000	0.001	0.002	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.003	0.000	0.003	0.003	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.003	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.001	0.000	0.001	0.001	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.001	0.000	0.001	0.001	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.003	0.000	0.002	0.003	3
09/10/90	294	0.003	0.000	0.002	0.003	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.001	0.000	0.001	0.001	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.001	0.000	0.001	0.001	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.001	0.000	0.001	0.002	3
OVERALL		0.002	0.001	0.001	0.004	39
C.V.		50.55%				

PARAMETER: Diss. Iron INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.173	0.012	0.156	0.182	3
12/12/89	22	0.244	0.007	0.235	0.252	3
01/02/90	43					0
01/09/90	50	0.133	0.008	0.125	0.145	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.087	0.009	0.076	0.094	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.215	0.007	0.206	0.223	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.016	0.002	0.014	0.019	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.102	0.049	0.054	0.169	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.028	0.001	0.027	0.030	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.039	0.002	0.037	0.041	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.026	0.002	0.023	0.029	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.035	0.021	0.006	0.053	3
09/10/90	294	0.035	0.021	0.006	0.053	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.105	0.005	0.099	0.112	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.006	0.001	0.005	0.007	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.026	0.012	0.014	0.043	3
OVERALL		0.093	0.077	0.005	0.252	39
C.V.		82.92%				

PARAMETER: Diss. Iron MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.031	0.004	0.027	0.037	3
12/12/89	22	0.018	0.001	0.017	0.019	3
01/02/90	43					0
01/09/90	50	0.010	0.002	0.007	0.013	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.071	0.001	0.070	0.072	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.034	0.004	0.028	0.038	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.011	0.000	0.011	0.012	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.026	0.002	0.024	0.028	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.248	0.005	0.242	0.253	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.176	0.005	0.169	0.180	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.206	0.012	0.193	0.221	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.151	0.043	0.119	0.212	3
09/10/90	294	0.151	0.043	0.119	0.212	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.049	0.003	0.045	0.052	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.017	0.002	0.015	0.020	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.026	0.015	0.015	0.048	3
OVERALL		0.081	0.082	0.007	0.253	39
C.V.		1.012				

PARAMETER: Diss. Iron EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.034	0.005	0.027	0.038	3
12/12/89	22	0.083	0.001	0.081	0.084	3
01/02/90	43					0
01/09/90	50	0.028	0.002	0.027	0.031	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.099	0.004	0.096	0.104	3
02/12/90	84	no data: winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.223	0.015	0.201	0.234	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.119	0.010	0.104	0.127	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.280	0.000	0.247	0.343	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.053	0.004	0.047	0.057	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.261	0.000	0.191	0.306	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.091	0.000	0.084	0.099	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.037	0.002	0.034	0.040	3
09/10/90	294	0.037	0.002	0.034	0.040	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.045	0.001	0.043	0.046	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.116	0.001	0.114	0.117	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.074	0.012	0.063	0.090	3
OVERALL		0.113	0.086	0.027	0.343	39
C.V.		76.22%				

PARAMETER: Diss. Potassium INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	92.000	0.000	92.000	92.000	3
12/12/89	22	92.667	0.471	92.000	93.000	3
01/02/90	43					0
01/09/90	50	70.333	0.471	70.000	71.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	57.667	0.471	57.000	58.000	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	24.667	0.471	24.000	25.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	37.667	0.471	37.000	38.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	26.000	0.816	25.000	27.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	42.667	0.471	42.000	43.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	52.667	1.247	51.000	54.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	26.333	0.943	25.000	27.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	49.000	0.816	48.000	50.000	3
09/10/90	294	49.000	0.816	48.000	50.000	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	111.000	4.546	106.000	117.000	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	29.000	2.160	26.000	31.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	56.333	1.247	55.000	58.000	3
OVERALL		54.744	27.863	24.000	117.000	39
C.V.		50.53%				

PARAMETER: Diss. Potassium MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	58.667	0.471	58.000	59.000	3
12/12/89	22	54.333	0.471	54.000	55.000	3
01/02/90	43					0
01/09/90	50	36.333	0.471	36.000	37.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	32.333	0.471	32.000	33.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	19.333	0.471	19.000	20.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	31.667	0.471	31.000	32.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	27.333	0.471	27.000	28.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	21.667	0.471	21.000	22.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	32.000	0.000	32.000	32.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	17.000	0.816	16.000	18.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	16.000	0.000	16.000	16.000	3
09/10/90	294	16.000	0.000	16.000	16.000	3
09/18/90	302					0
09/25/90	309					0
10/02/90 to	316	32.667	0.471	32.000	33.000	3
01/28/91	434					0
02/04/91	441	10.667	0.471	10.000	11.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	25.000	0.816	24.000	26.000	3
OVERALL		30.000	13.602	10.000	59.000	39
C.V.		0.453				

PARAMETER: Diss. Potassium EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	47.667	0.943	47.000	49.000	3
12/12/89	22	59.000	0.000	59.000	59.000	3
01/02/90	43					0
01/09/90	50	33.667	0.471	33.000	34.000	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	27.667	0.471	27.000	28.000	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	15.000	0.000	15.000	15.000	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	26.000	0.000	26.000	26.000	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	22.667	0.000	22.000	23.000	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	23.667	0.471	23.000	24.000	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	22.333	0.000	22.000	23.000	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	2.667	0.000	2.000	3.000	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	24.000	0.000	24.000	24.000	3
09/10/90	294	24.000	0.000	24.000	24.000	3
09/16/90	302					0
09/25/90	309					0
10/02/90	316	34.667	0.471	34.000	35.000	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	2.667	0.471	2.000	3.000	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	22.000	0.000	22.000	22.000	3
OVERALL		26.282	15.040	2.000	59.000	39
C.V.		57.23%				

PARAMETER: Diss. Manganese INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.182	0.000	0.182	0.183	3
12/12/89	22	0.149	0.002	0.146	0.150	3
01/02/90	43					0
01/09/90	50	0.086	0.001	0.085	0.088	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.049	0.001	0.048	0.050	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.262	0.002	0.261	0.265	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.156	0.002	0.154	0.158	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.096	0.001	0.095	0.098	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.059	0.001	0.058	0.060	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.056	0.002	0.053	0.058	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.037	0.001	0.035	0.038	3
08/06/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.025	0.017	0.001	0.037	3
09/10/90	294	0.025	0.017	0.001	0.037	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.022	0.001	0.021	0.024	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.305	0.022	0.276	0.327	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.297	0.013	0.283	0.314	3
OVERALL		0.114	0.088	0.001	0.327	39
C.V.		77.24%				

PARAMETER: Diss. Manganese MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.020	0.001	0.019	0.021	3
12/12/89	22	0.024	0.000	0.024	0.025	3
01/02/90	43					0
01/09/90	50	0.013	#NUM!	0.013	0.013	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.078	0.001	0.077	0.079	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.019	0.000	0.019	0.020	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.019	0.000	0.018	0.019	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.037	0.001	0.036	0.038	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.214	0.006	0.207	0.221	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.239	0.004	0.234	0.245	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.493	0.005	0.487	0.500	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.067	0.001	0.066	0.068	3
09/10/90	294	0.067	0.001	0.066	0.068	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.026	0.002	0.024	0.028	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.092	0.002	0.089	0.093	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.010	0.000	0.010	0.011	3
OVERALL		0.103	0.133	0.013	0.500	39
C.V.		1.291				

PARAMETER: Diss. Manganese EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.047	0.001	0.046	0.048	3
12/12/89	22	0.167	0.000	0.166	0.167	3
01/02/90	43					0
01/09/90	50	0.041	0.000	0.041	0.042	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.261	0.000	0.260	0.261	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.354	0.003	0.350	0.356	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.181	0.002	0.178	0.183	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.758	0.000	0.757	0.760	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.168	0.001	0.167	0.169	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.879	0.000	0.848	0.915	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.420	0.000	0.419	0.423	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.094	0.001	0.093	0.095	3
09/10/90	294	0.094	0.001	0.093	0.095	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.083	0.004	0.078	0.088	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.229	0.000	0.229	0.230	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	1.197	0.012	1.180	1.210	3
OVERALL		0.283	0.254	0.041	0.915	39
C.V.		89.55%				

PARAMETER: Diss Zinc INFLUENT units: mg/L

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0	0.012	0.002	0.010	0.015	3
12/12/89	22	0.007	0.001	0.006	0.008	3
01/02/90	43					0
01/09/90	50	0.010	0.003	0.006	0.014	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.016	0.003	0.012	0.019	3
02/12/90	84		no data; winter freeze-up			0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112		no data			0
03/19/90	119	0.006	0.002	0.004	0.009	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.008	0.005	0.004	0.015	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.008	0.008	0.002	0.019	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.012	0.005	0.007	0.018	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.005	0.003	0.003	0.009	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.010	0.003	0.008	0.014	3
OVERALL		0.007	0.006	0.002	0.019	39
C.V.		78.52%				

PARAMETER: Diss. Zinc MIDPOINT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43					0
01/09/90	50	0.042	0.057	0.002	0.123	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.002	0.000	0.002	0.002	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.002	0.000	0.002	0.002	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.002	0.000	0.002	0.002	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.002	0.000	0.002	0.002	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.006	0.000	0.005	0.006	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.005	0.001	0.004	0.007	3
OVERALL		0.005	0.019	0.002	0.123	39
C.V.		3.548				

PARAMETER: Diss. Zinc EFFLUENT units: mg/L

DATE	DAY	AVG	STD	MIN	MAX	n
11/20/89	0	0.002	0.000	0.002	0.002	3
12/12/89	22	0.002	0.000	0.002	0.002	3
01/02/90	43					0
01/09/90	50	0.003	0.001	0.002	0.005	3
01/16/90	57					0
01/23/90	64					0
01/31/90	72					0
02/05/90	77	0.003	0.000	0.003	0.004	3
02/12/90	84	no data; winter freeze-up				0
02/19/90	91					0
02/27/90	99					0
03/06/90	106					0
03/12/90	112	no data				0
03/19/90	119	0.018	0.009	0.011	0.031	3
03/26/90	126					0
04/03/90	134					0
04/10/90	141	0.002	0.000	0.002	0.002	3
04/16/90	147					0
04/23/90	154					0
04/30/90	161					0
05/08/90	169	0.004	0.000	0.003	0.005	3
05/14/90	175					0
05/22/90	183					0
05/25/90	186					0
06/04/90	196	0.002	0.000	0.002	0.002	3
06/11/90	203					0
06/18/90	210					0
06/25/90	217					0
07/03/90	225	0.002	0.000	0.002	0.002	3
07/09/90	231					0
07/16/90	238					0
07/23/90	245					0
07/30/90	252	0.002	0.000	0.002	0.002	3
08/08/90	261					0
08/13/90	266					0
08/20/90	273					0
08/27/90	280					0
09/04/90	288	0.002	0.000	0.002	0.002	3
09/10/90	294	0.002	0.000	0.002	0.002	3
09/18/90	302					0
09/25/90	309					0
10/02/90	316	0.004	0.001	0.003	0.005	3
10/09/90 to	323					0
01/28/91	434					0
02/04/91	441	0.003	0.000	0.003	0.004	3
02/11/91	448					0
02/18/91	455					0
02/25/91	462					0
03/04/91	469					0
03/08/91	473					0
03/18/91	483					0
03/27/91	492					0
03/31/91	496	0.006	0.002	0.004	0.009	3
OVERALL		0.004	0.005	0.002	0.031	39
C.V.		127.72%				

Appendix B-1

Surface Water Quality Data and Discussion of Metals Concentrations

ALUMINUM

Aluminum concentrations were consistently low. Total Al consisted predominantly of particulate matter. Average concentrations of total Al were 0.487 mg/L (4% dissolved) in the influent, 0.047 mg/L (23% dissolved) in the midpoint, and 0.042 mg/L (29% dissolved) in the effluent. Variability was greatest in the influent (C.V.=104%, due to peak values in late fall and early summer), followed by the effluent (C.V.=46%) and the midpoint (C.V.=39%). Seasonal changes in total and dissolved Al are shown in Figures B-1-1 and B-1-2, respectively. There was a decrease in total Al from winter to summer, followed by an increase with the onset of fall rains (Figure B-1-1). This trend follows a decrease in particulate Al, as reflected by the increasing dissolved Al during the same period. Dissolved Al at all locations tended to increase through the growing season, with peak influent values occurring probably in association with rainfall events. During the growing season, values in the midpoint and effluent samples were usually higher than in the influent, reflecting release of dissolved Al from biomass decay. During the fall and winter, dissolved Al tended to be removed in the wetland.

Seasonal trends in total and dissolved Al concentrations during Year 3 were generally similar to Years 2 and 1. While the range of concentrations during Year 1 was higher, reflecting the effects of wetland construction, concentration ranges were similar during Years 2 and 3.

COPPER

Copper concentrations, as with Al, were consistently low. Total copper (Cu) concentrations were usually higher in the influent than in the midpoint and effluent, and consisted primarily of dissolved copper. Average concentrations were 0.004 mg/L (50% dissolved Cu) in the influent, and 0.002 mg/L (100% dissolved Cu) in both the midpoint and effluent samples. The coefficient of variability was similar in the influent and effluent (70% and 75% respectively), and was lowest at the midpoint (39%). The seasonal trends for total and dissolved Cu are shown in Figures B-1-3 and B-1-4. Peak influent total Cu concentrations occurred during fall and spring rains, with a smaller maximum occurring during the summer drought. An increase in dissolved Cu also occurred during this period, and probably reflects the concentrating effects of water loss through evaporation and transpiration. There was little difference in total Cu content in the midpoint and effluent samples throughout the year.

TOTAL ALUMINUM CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

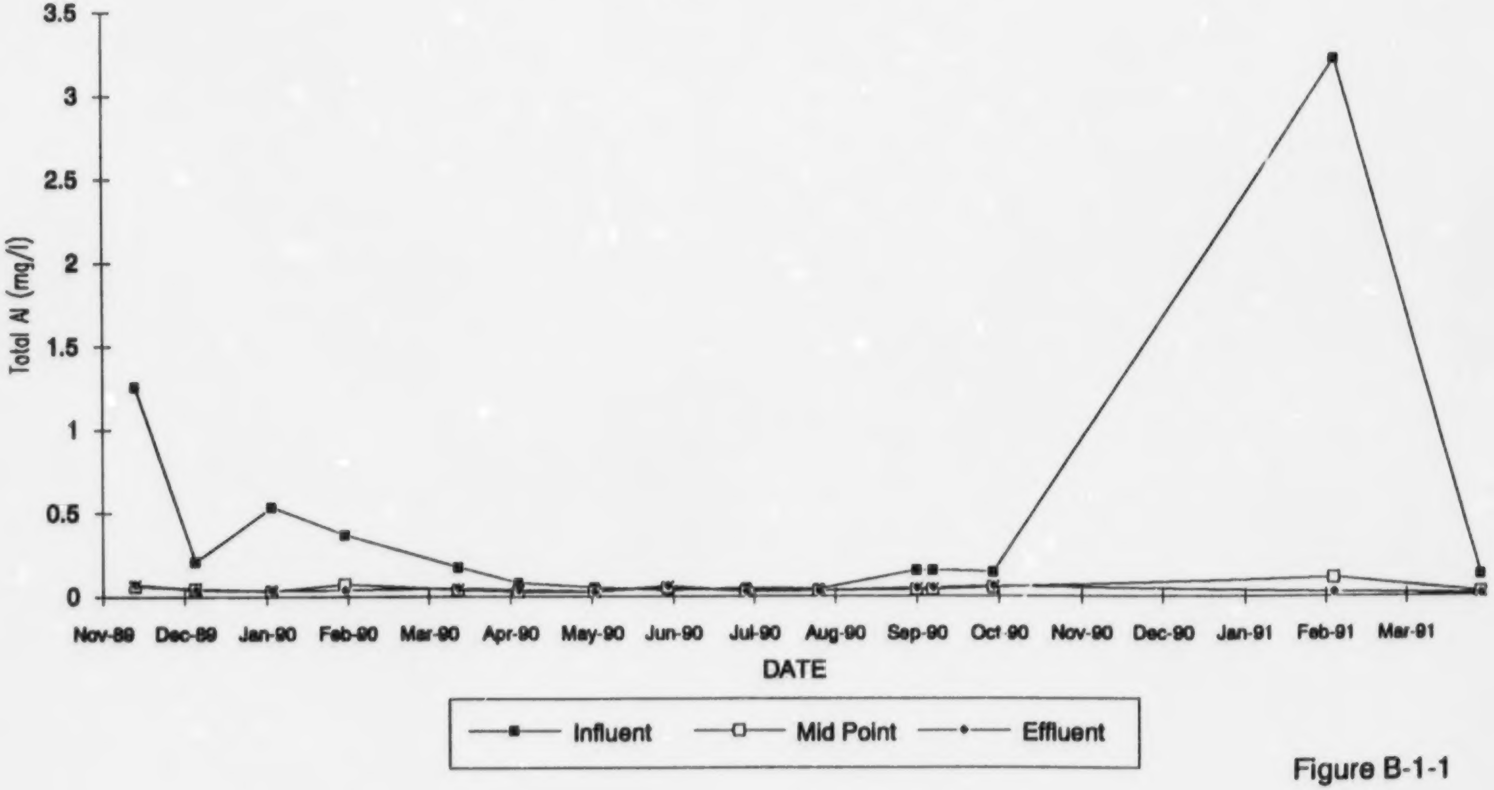


Figure B-1-1

DISSOLVED ALUMINUM CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

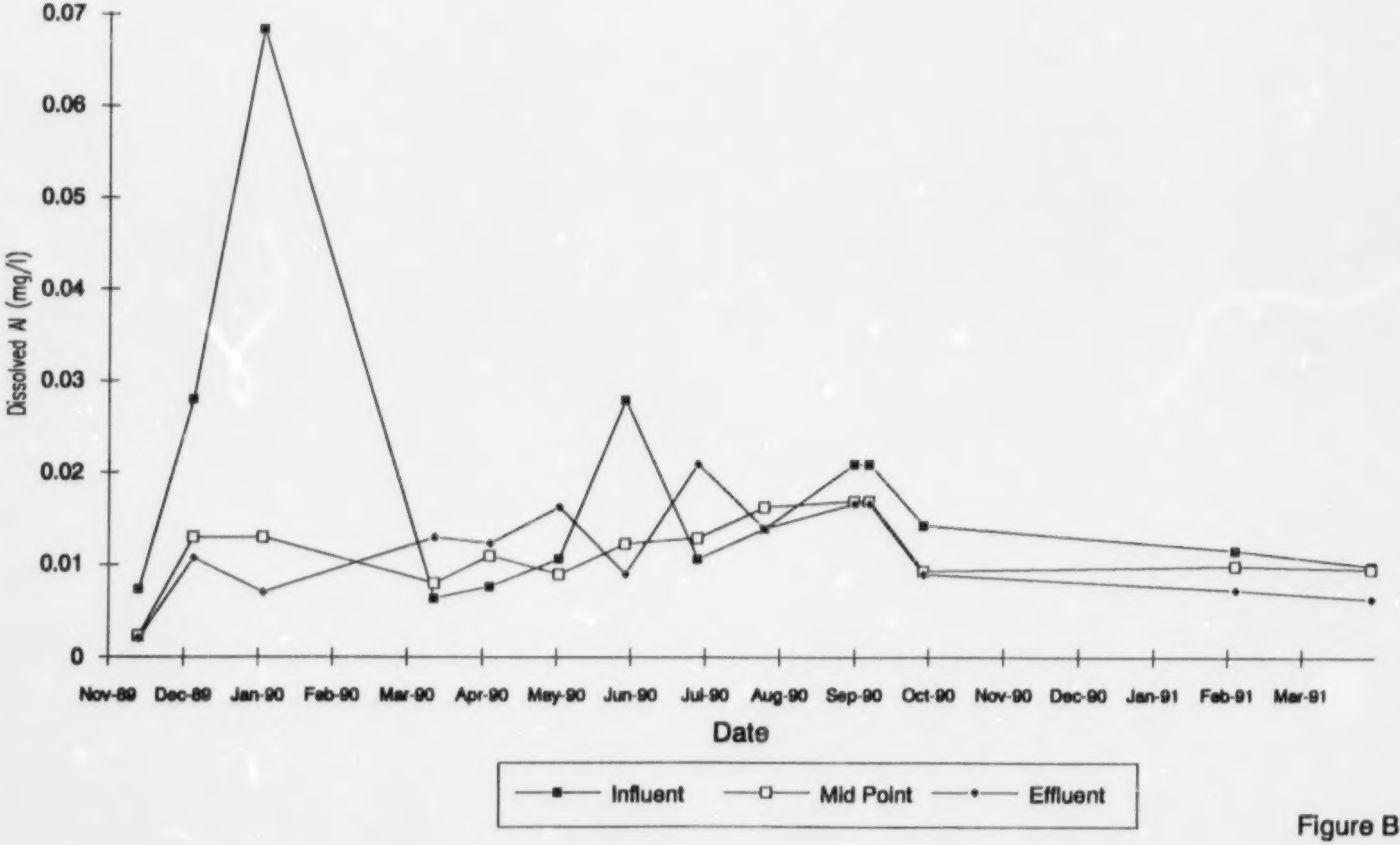


Figure B-1-2

TOTAL COPPER CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

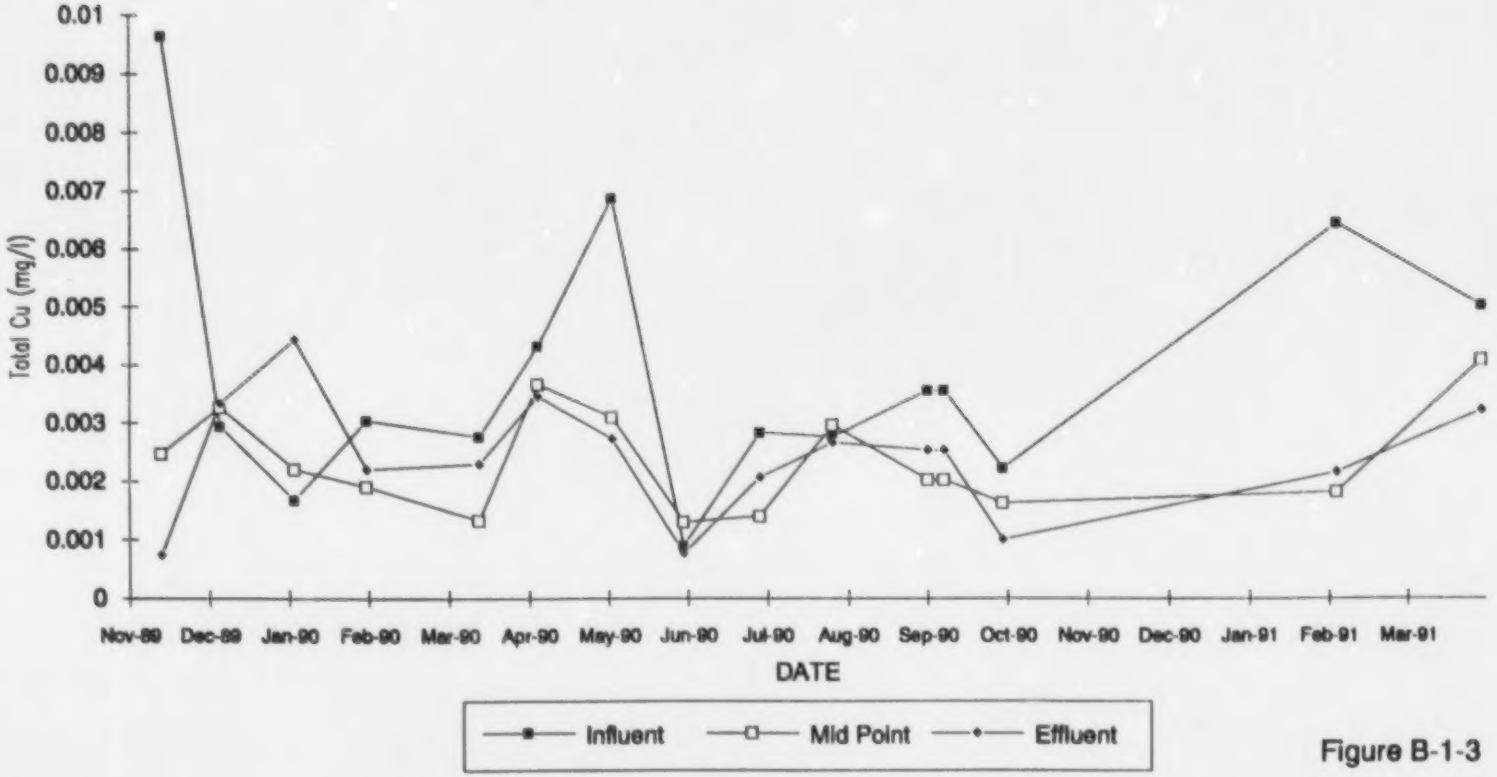


Figure B-1-3

DISSOLVED COPPER CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

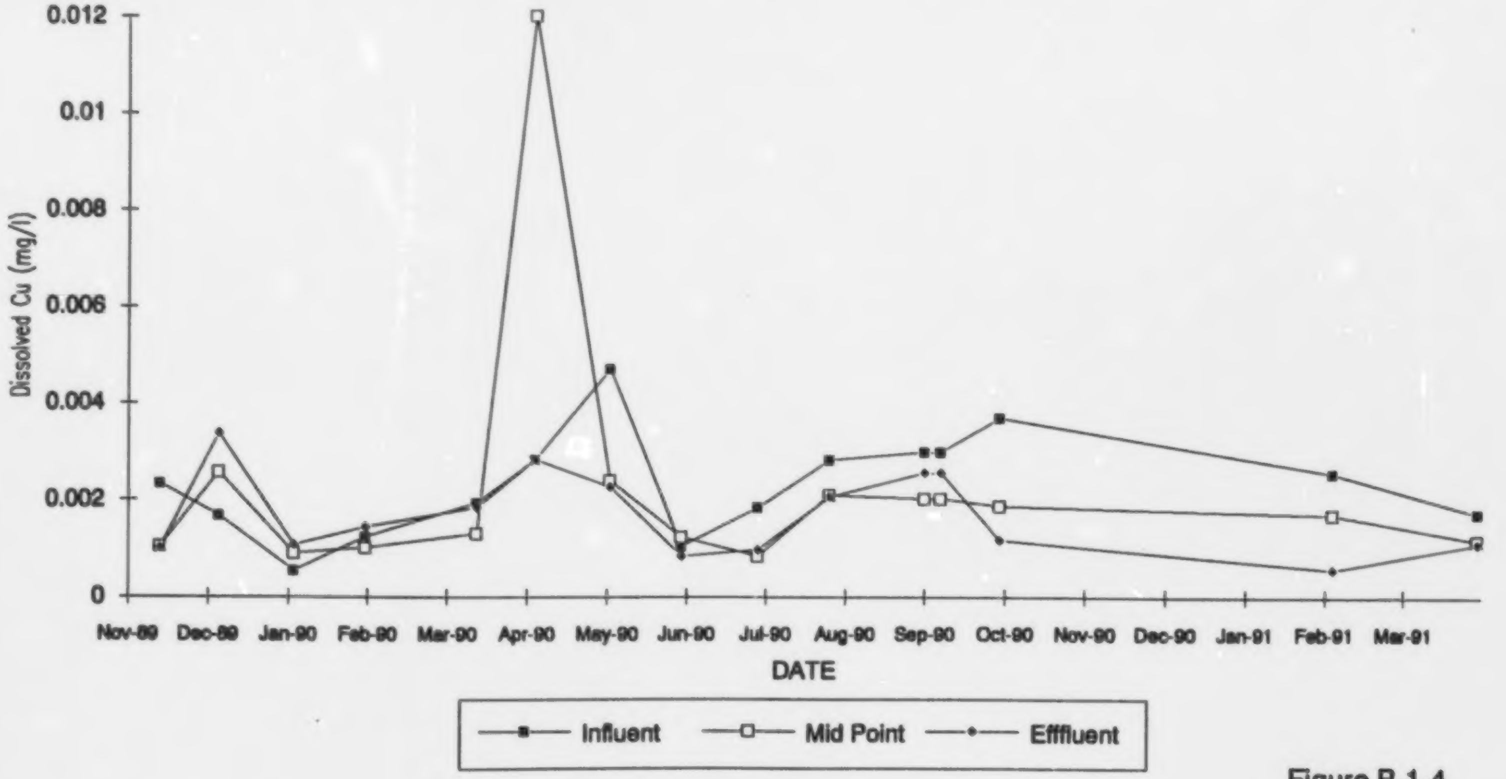


Figure B-1-4

The concentration ranges of total copper in the wetland were similar among the three different years of the study. Dissolved Cu appears to have increased overall during Years 2 and 3 in relation to Year 1. Seasonal trends in total Cu concentrations during Year 3 were different from Years 1 and 2. Generally, total copper concentrations increased through the wetland during the first two growing seasons, whereas total Cu tended to decrease during the same period in Year 3. The changes in dissolved Cu were similar between years.

IRON

Total iron (Fe) consisted primarily of particulate Fe. Average total Fe concentrations were 0.779 mg/L (12% particulate) in the influent, 0.234 mg/L (35% particulate) in the midpoint, and 0.113 mg/L (40% particulate) in the effluent. The coefficient of variability was high at all sample sites (83%, 112% and 60%, respectively). Concentrations of total Fe were higher in the influent than in the midpoint and effluent samples during most of the year, with small deviations from this pattern occurring during the growing season (Figure B-1-5). Peak influent total Fe concentrations occurred, as with Cu, in association with rainfall events. Evaporative concentration of dissolved Fe was not evident during the summer drought, as dissolved Fe values in both the midpoint and effluent tended to decrease between early July and early September (Figure B-1-6).

The range of total Fe concentrations was highest in Year 1, and was similar in Years 2 and 3. Seasonal trends during Years 2 and 3 were similar, with a tendency of the wetland to export dissolved Fe during the early growing season.

POTASSIUM

Total potassium (K) concentrations in the experimental wetland were high because of the dosing with KNO_3, and comprised mostly dissolved K. Average total K was 53.3 mg/L (100% dissolved) in the influent, 30.6 mg/L (98% dissolved) in the midpoint and 26.8 mg/L (98% dissolved). The coefficient of variability was high at all three locations (49%, 44% and 57%, respectively). Seasonal trends for both total and dissolved K were very similar (Figures B-1-7 and B-1-8, respectively. Because the primary K source was the nitrate dosing, concentrations of K largely paralleled the levels of NO_3 (Figure 4.5.6-3). Evaporative concentration during the summer drought did not occur with this metal. It is interesting to note that, while K values in the influent and effluent decreased in response to the interruption of KNO_3 dosing between October 1990 and February 1991, midpoint K remained constant. The reason for this pattern has not been discerned.

Potassium concentration ranges and seasonal trends were similar during the three years of the study. This is because of the relationship between K concentrations and nitrate dosing.

TOTAL IRON CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

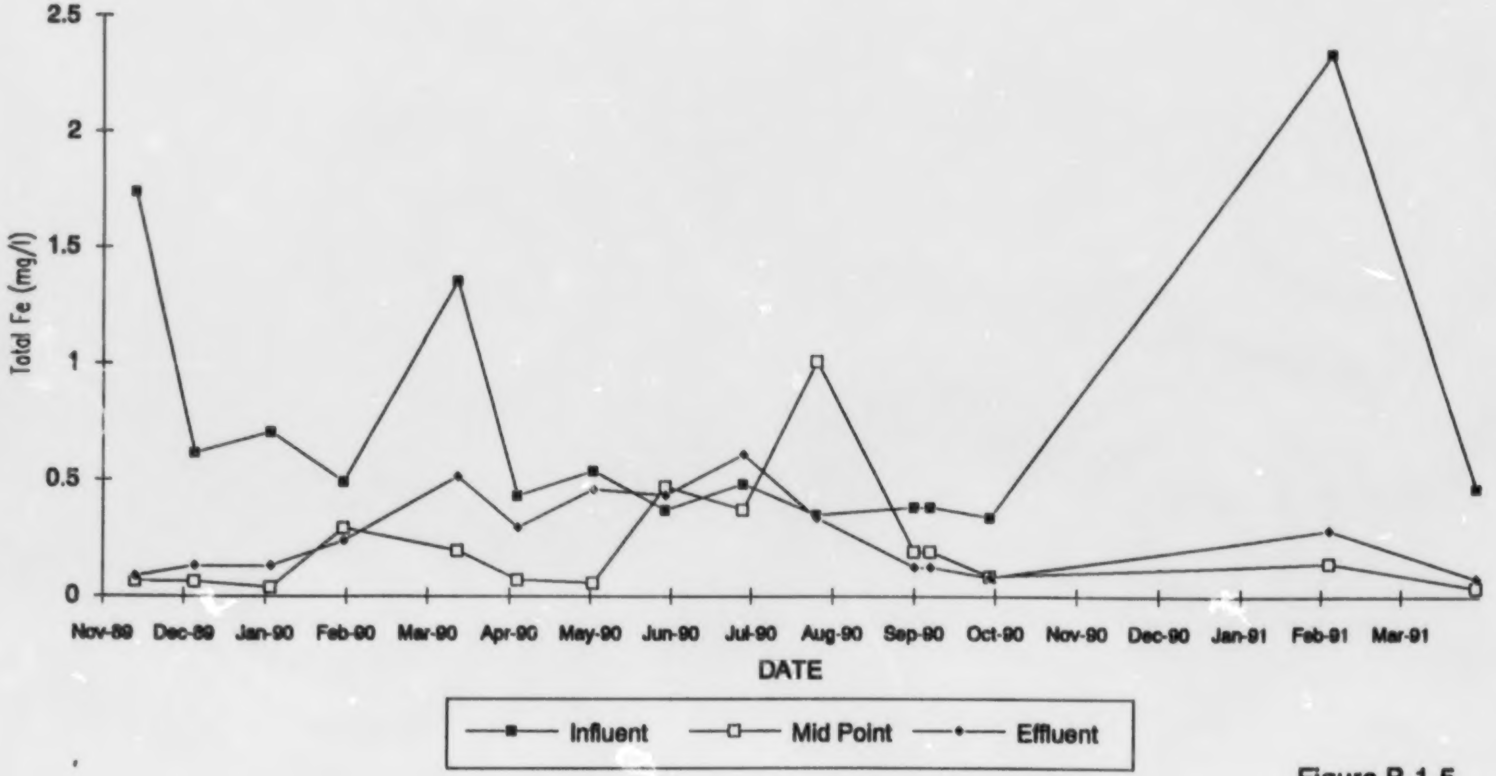


Figure B-1-5

DISSOLVED IRON CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE
EXPERIMENTAL WETLAND 1989 - 1991

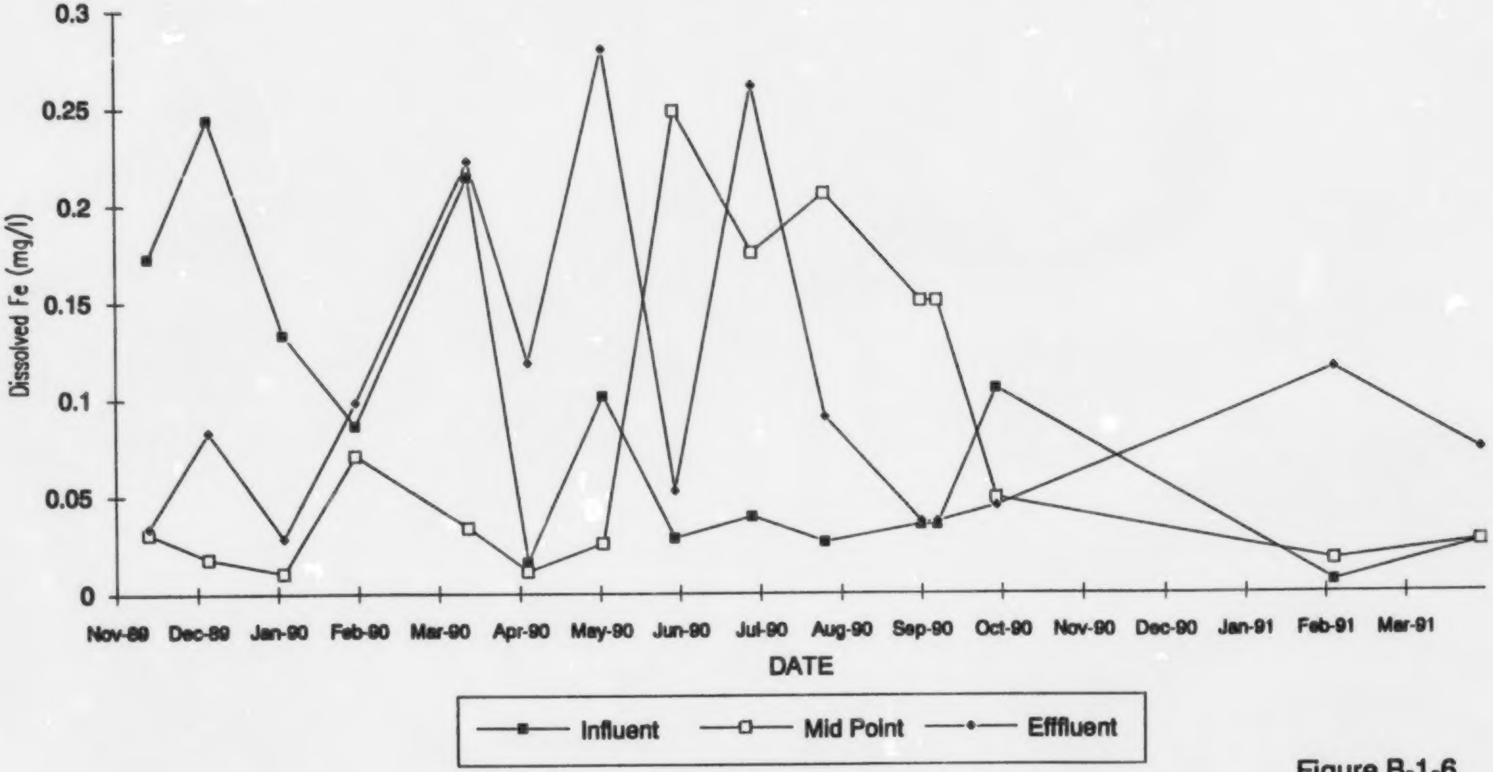


Figure B-1-6

TOTAL POTASSIUM CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

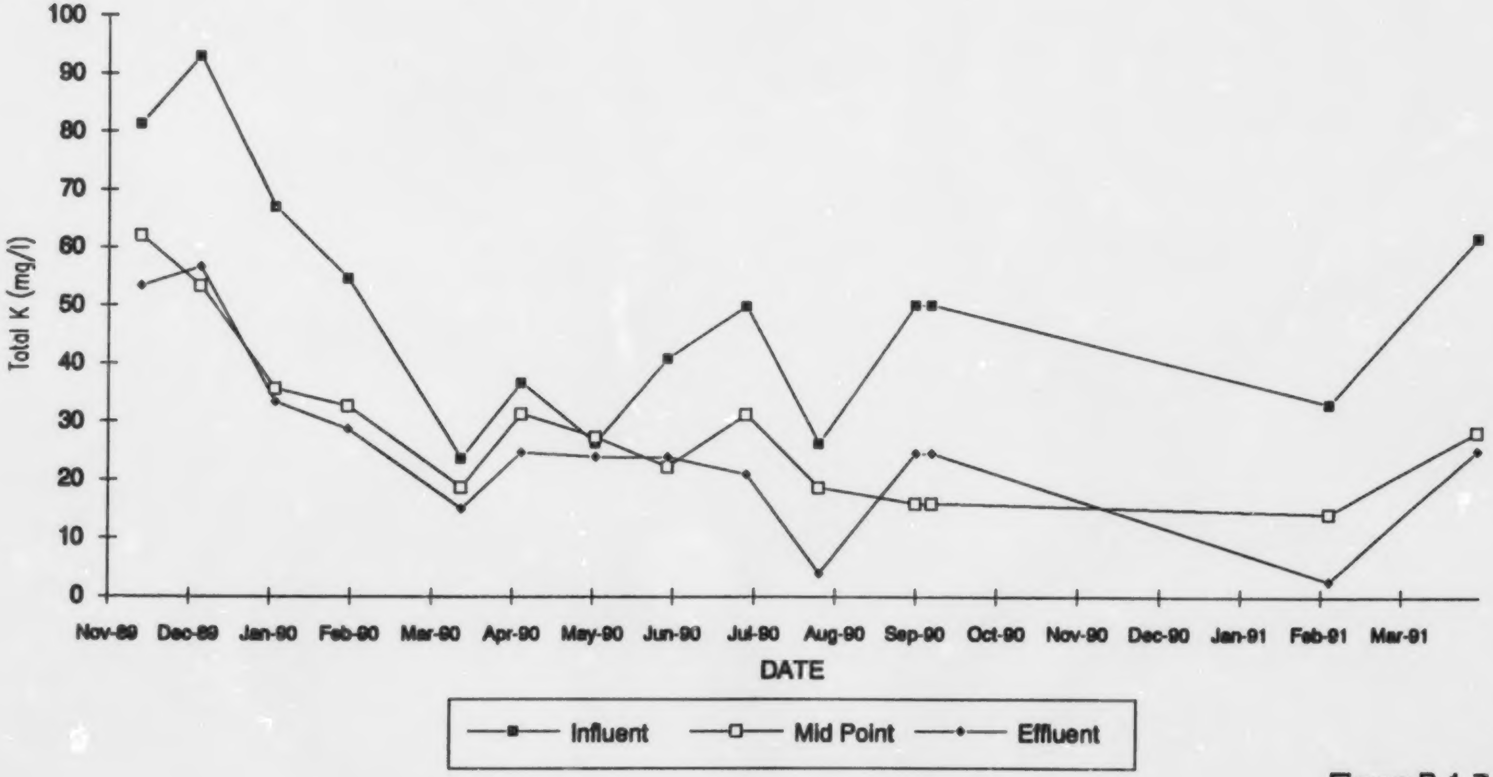


Figure B-1-7

DISSOLVED POTASSIUM CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

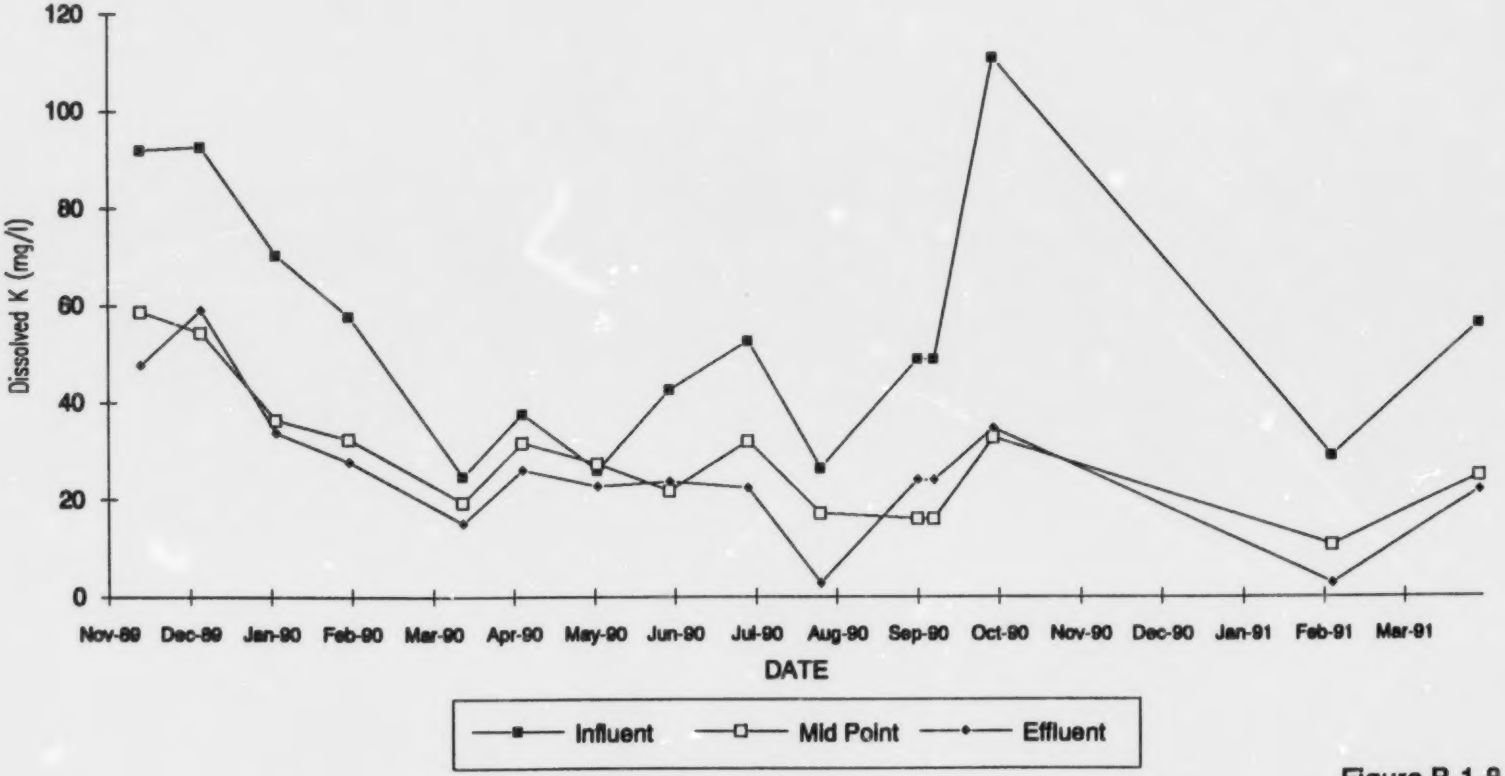


Figure B-1-8

MANGANESE

Total manganese (Mn) in the samples consisted almost entirely of dissolved Mn. Average total Mn concentrations during Year 3 were 0.134 mg/L (85% dissolved) in the influent, 0.114 mg/L (90% dissolved) in the midpoint, and 0.317 mg/L (89% dissolved) in the effluent. Coefficients of variability were high, ranging from 79% in the influent, to 119% and 81% in the midpoint and effluent, respectively. Seasonal trends for total and dissolved Mn concentrations are shown in Figures B-1-9 and B-1-10. Mn values at the midpoint and effluent were usually higher than in the influent. Peak influent Mn content occurred in the spring and tended to decrease through the growing season. Manganese at the midpoint tended to be lower than, and parallel to, influent Mn during the winter and early spring 1990, but increased markedly during the growing season to levels several times higher than in the influent, although dropping during the latter part of the summer drought. Effluent Mn tended to increase during winter and late spring, and displayed considerable variation (including maximum levels) during the growing season, dropping late during the summer drought.

Manganese concentrations between years were not compared, as Mn data were collected during Year 3 only.

ZINC

Total zinc (Zn) occurred almost entirely in dissolved rather than particulate form, and concentrations were low. Average Zn concentrations in the influent were 0.007 mg/L (100% dissolved), and 0.004 mg/L (100% dissolved) in the midpoint and 0.005 mg/L (80% dissolved) in the effluent. Coefficients of variability ranged from 62% in the influent to 88% in the midpoint and 103% in the effluent. Seasonal trends for total and dissolved Zn are shown in Figures B-1-11 and B-1-12. Total Zn concentrations in the influent were initially higher than in the midpoint and effluent, and tended to decrease steadily through the winter, spring and the ensuing 1990 growing season, rising markedly in the following fall and winter. Midpoint total Zn tended to rise during fall and winter of 1989 and decline overall during the ensuing 1990 growing season, increasing markedly over the following winter and again dropping by early spring. Zn in the effluent was similar to and largely parallelled the midpoint during the winter and spring 1990, increasing and decreasing markedly during the first and latter halves of the growing season, respectively, then rising markedly during the fall and winter and dropping again by late spring. Comparison of the trends shown in Figures B-1-11 and B-1-12. Much of the variability in total Zn at any time of year was due to increases in particulate matter.

The range of total Zn concentrations was generally lowest during Year 1, highest during Year 2, and similar in Years 1 and 3. This pattern, while not a concern from a water quality standpoint, may reflect Zn exports from mining activities to the experimental system. Major expansion of mining operations took place during Year 2. Dissolved Zn was similar among years. Removal of total Zn generally occurred through the wetland during the growing season, although some export of particulate Zn occurred in the lower wetland basin.

TOTAL MANGANESE CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

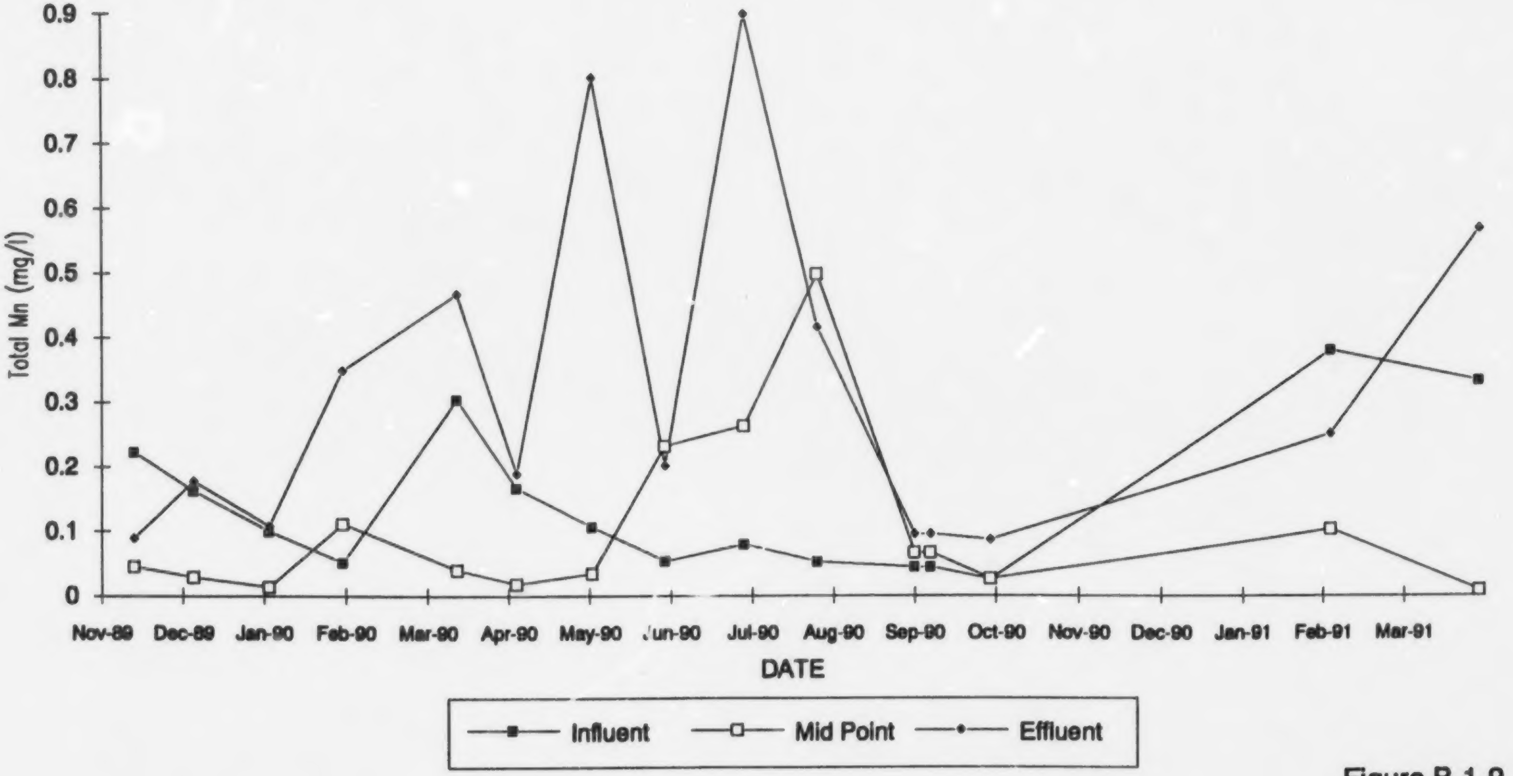


Figure B-1-9

DISSOLVED MANGANESE CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

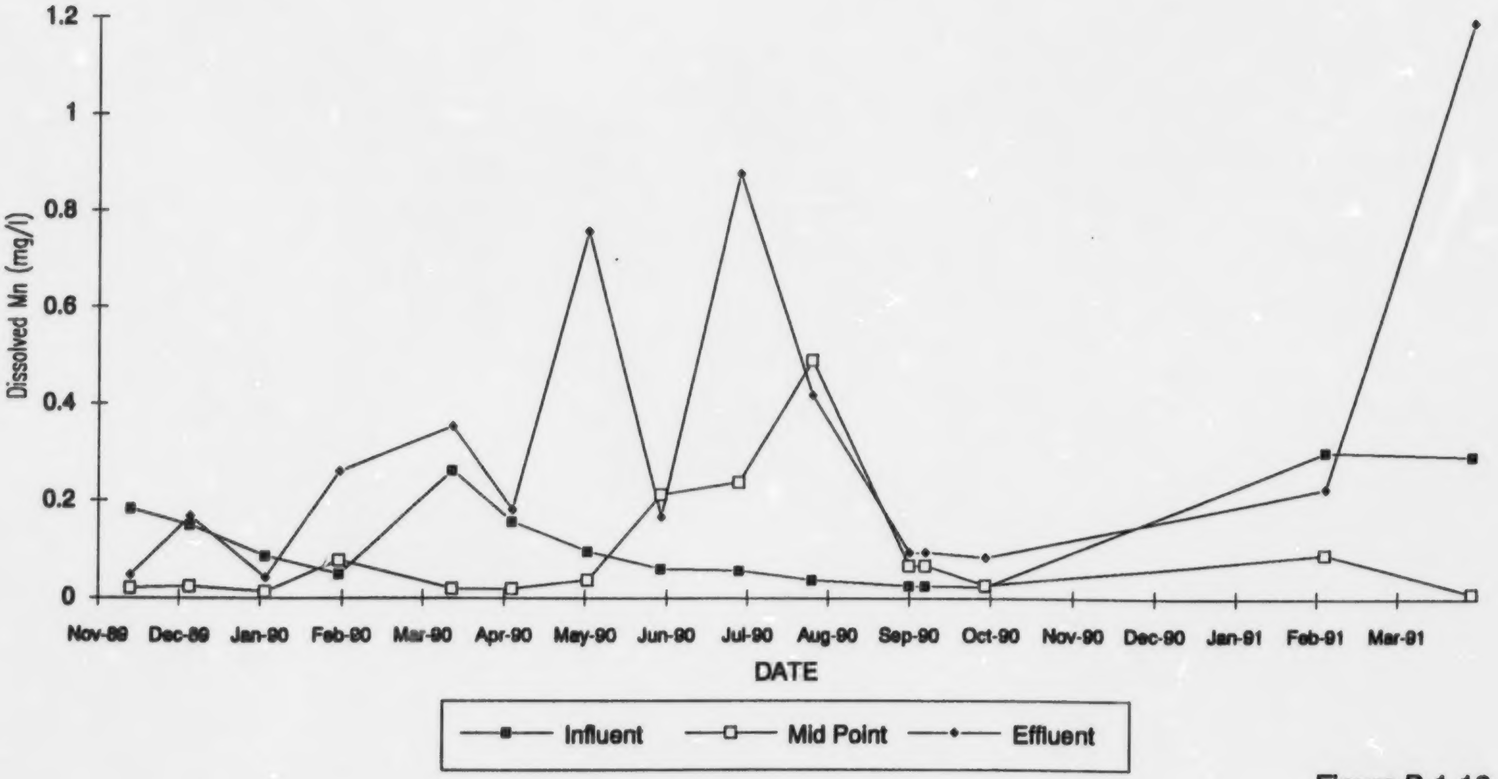


Figure B-1-10

TOTAL ZINC CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL
WETLAND 1989 - 1991

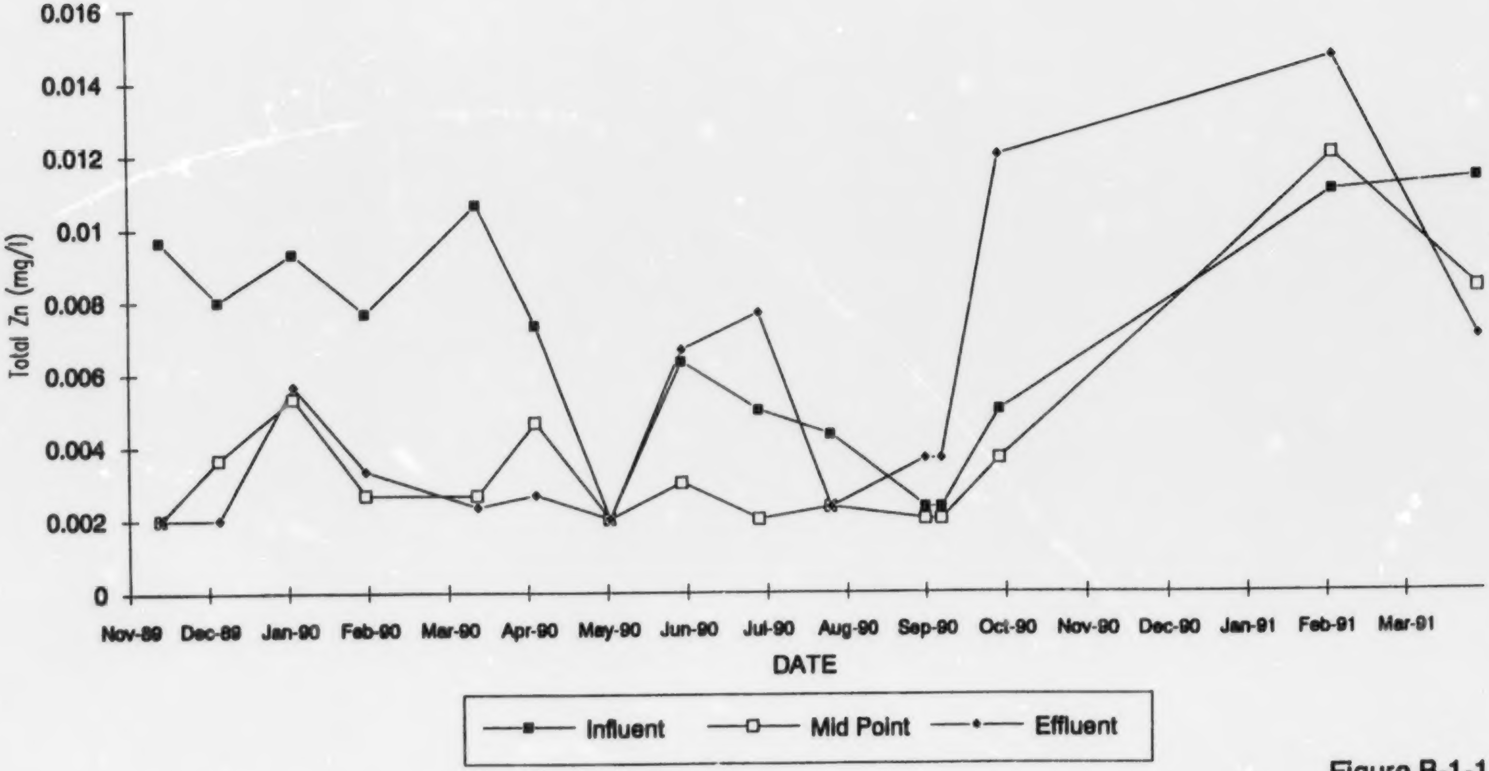


Figure B-1-11

DISSOLVED ZINC CONCENTRATIONS IN THE INFLUENT, MIDPOINT AND EFFLUENT OF THE EXPERIMENTAL WETLAND 1989 - 1991

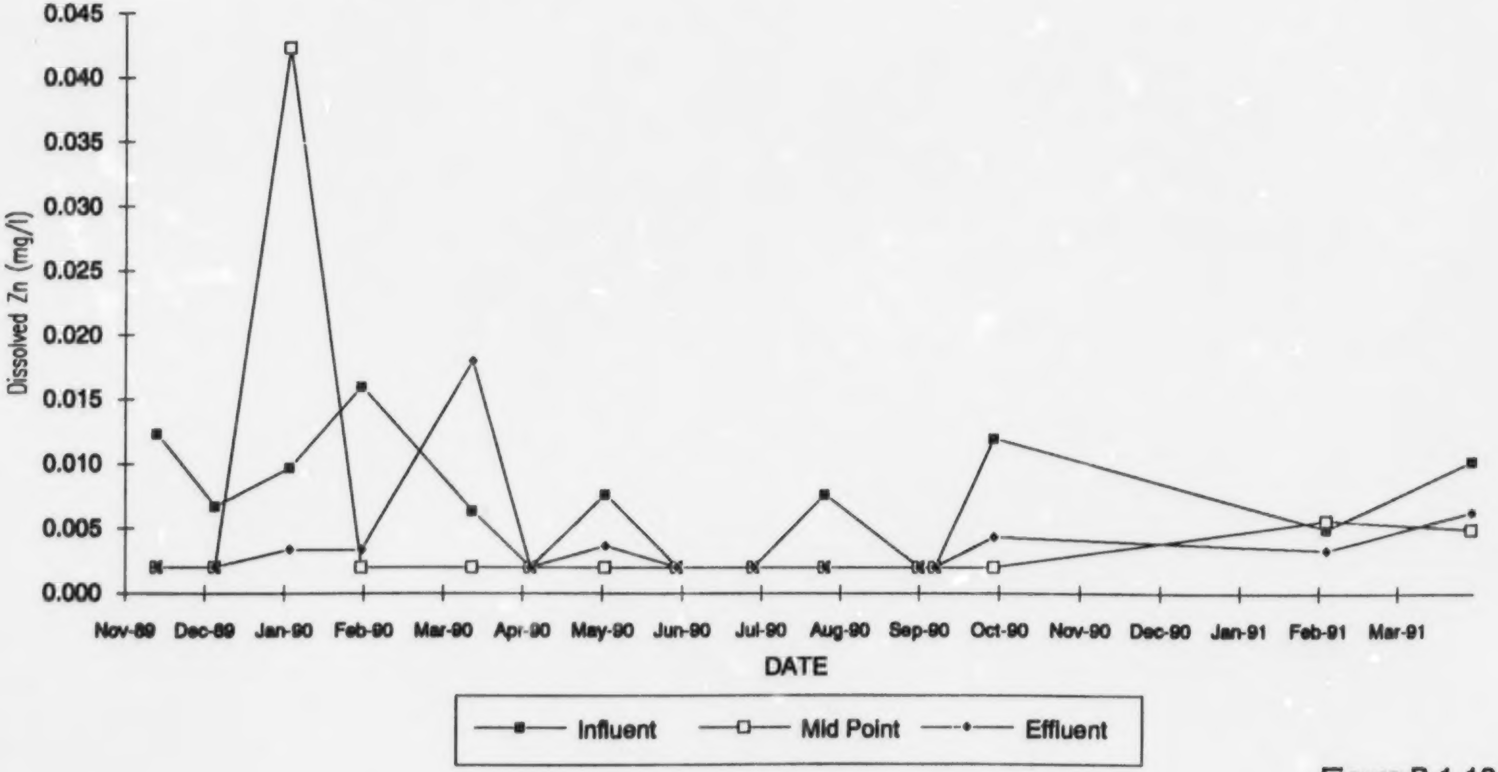


Figure B-1-12

Appendix B-2

Groundwater Quality Data

PARAMETER: pH units: Rel. Units
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	5.90	0.00	5.90	5.90	1
05/15/90	176	5.65	0.15	5.50	5.80	2
07/10/90	232	6.00	0.00	6.00	6.00	1
03/27/91	492	5.80	0.00	5.80	5.80	1
OVERALL		5.80	0.17	5.50	6.00	5
C.V.		3%				

PARAMETER: pH units: Rel. Units
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	6.30	0.00	6.30	6.30	1
05/15/90	176	5.85	0.15	5.70	6.00	2
07/10/90	232	6.10	0.00	6.10	6.10	1
03/27/91	492	5.90	0.00	5.90	5.90	1
OVERALL		6.00	0.20	5.70	6.30	5
C.V.		3%				

PARAMETER: Conductivity units: umho/cm
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	No.
11/20/89	0					
03/27/90	127	241	0	241	241	1
05/15/90	176	290	4	286	294	2
07/10/90	232	290	0	290	290	1
03/27/91	492	259	0	259	259	1
OVERALL		274	21	241	294	5
C.V.		8%				

PARAMETER: Conductivity units: umho/cm
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	No.
11/20/89	0					
03/27/90	127	136	0	136	136	1
05/15/90	176	158	6	152	164	2
07/10/90	232	167	0	167	167	1
03/27/91	492	309	0	309	309	1
OVERALL		186	63	136	309	5
C.V.		34%				

PARAMETER: Suspended solids units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: BASIN 1 GROUNDWATER

DATE	DAY No.	AVG	STD	MIN	MAX	n
03/27/90	127			0	0	0
05/15/90	176	6	1	5	7	2
07/10/90	232			0	0	0
OVERALL		6	1	5	7	2
C.V.		17%				

PARAMETER: Suspended solids units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: BASIN 2 GROUNDWATER

DATE	DAY No.	AVG	STD	MIN	MAX	n
03/27/90	127					0
05/15/90	176	26	6	20	32	2
07/10/90	232					0
OVERALL		26	6	20	32	2
C.V.		23%				

PARAMETER: TOTAL ORGANIC CARBON units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
11/20/89	127					
05/15/90	176	21.50	0.50	21.00	22.00	2
07/10/90	232	19.00	0.00	19.00	19.00	1
03/27/91	492	30.00	0.00	30.00	30.00	1
OVERALL		23.00	4.18	19.00	30.00	4
C.V.		18%				

PARAMETER: TOTAL ORGANIC CARBON units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127					
05/15/90	176	23.50	3.50	20.00	27.00	2
07/10/90	232	34.00	0.00	34.00	34.00	1
03/27/91	492	21.00	0.00	21.00	21.00	1
OVERALL		25.50	5.59	20.00	34.00	4
C.V.		22%				

PARAMETER: TOTAL NITROGEN units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
11/20/89	127	2.40	0.00	2.40	2.40	1
05/15/90	176	5.75	0.15	5.60	5.90	2
07/10/90	232	2.70	0.00	2.70	2.70	1
03/27/91	492	2.70	0.00	2.70	2.70	1
OVERALL		3.86	1.55	2.40	5.90	5
C.V.		40%				

PARAMETER: TOTAL NITROGEN units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	2.80	0.00	2.80	2.80	1
05/15/90	176	5.55	0.25	5.30	5.80	2
07/10/90	232	3.50	0.00	3.50	3.50	1
03/27/91	492	3.80	0.00	3.80	3.80	1
OVERALL		4.24	1.13	2.80	5.80	5
C.V.		27%				

PARAMETER: Nitrate nitrogen units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.002	0.000	0.002	0.002	1
05/15/90	176	0.007	0.000	0.007	0.007	2
07/10/90	232	0.002	0.000	0.002	0.002	1
03/27/91	492	0.017	0.000	0.017	0.017	1
OVERALL		0.007	0.005	0.002	0.017	5
C.V.		78%				

PARAMETER: Nitrate nitrogen units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.002	0.000	0.002	0.002	1
05/15/90	176	0.004	0.004	0.000	0.007	2
07/10/90	232	0.003	0.000	0.003	0.003	1
03/27/91	492	0.010	0.000	0.010	0.010	1
OVERALL		0.004	0.004	0.000	0.010	5
C.V.		82%				

PARAMETER: Ammonia (NH3) units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
11/20/89	127	1.820	0.000	1.820	1.820	1
05/15/90	176	4.930	0.090	4.840	5.020	2
07/10/90	232	1.870	0.000	1.870	1.870	1
03/27/91	492	1.730	0.000	1.730	1.730	1
OVERALL		3.056	1.532	1.730	5.020	5
C.V.		50%				

PARAMETER: Ammonia (NH3) units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	1.690	0.000	1.690	1.690	1
05/15/90	176	5.040	0.080	4.960	5.120	2
07/10/90	232	1.890	0.000	1.890	1.890	1
03/27/91	492	2.520	0.000	2.520	2.520	1
OVERALL		3.236	1.499	1.690	5.120	5
C.V.		46%				

PARAMETER: Nitrite units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.012	0.000	0.012	0.012	1
05/15/90	176	0.004	0.000	0.004	0.004	2
07/10/90	232	0.002	0.000	0.002	0.002	1
03/27/91	492	0.004	0.000	0.004	0.004	1
OVERALL		0.005	0.003	0.002	0.012	5
C.V.		67%				

PARAMETER: Nitrite units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.010	0.000	0.010	0.010	1
05/15/90	176	0.004	0.000	0.004	0.004	2
07/10/90	232	0.002	0.000	0.002	0.002	1
03/27/91	492	0.002	0.000	0.002	0.002	1
OVERALL		0.004	0.003	0.002	0.010	5
C.V.		67%				

PARAMETER: Total Phosphorus units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
11/20/89	127	0.040	0.000	0.040	0.040	1
05/15/90	176	0.034	0.003	0.030	0.037	2
07/10/90	232	0.037	0.000	0.037	0.037	1
03/27/91	492	0.040	0.000	0.040	0.040	1
OVERALL		0.037	0.004	0.030	0.040	5
C.V.		10%				

PARAMETER: Total Phosphorus units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.042	0.000	0.042	0.042	1
05/15/90	176	0.050	0.010	0.040	0.060	2
07/10/90	232	0.088	0.000	0.088	0.088	1
03/27/91	492	0.075	0.000	0.075	0.075	1
OVERALL		0.061	0.019	0.042	0.088	5
C.V.		30%				

PARAMETER: Total Dissolved Phosphorus units: mg/L

AVERAGE CONCENTRATIONS

SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
11/20/89	127	0.020	0.000	0.020	0.020	1
05/15/90	176					0
07/10/90	232					0
03/27/91	492					0
OVERALL		0.020	0.000	0.020	0.020	1
C.V.		0%				

PARAMETER: Total Dissolved Phosphorus units: mg/L

AVERAGE CONCENTRATIONS

SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.013	0.000	0.013	0.013	1
05/15/90	176					0
07/10/90	232					0
03/27/91	492					0
OVERALL		0.013	0.000	0.013	0.013	1
C.V.		0%				

PARAMETER: Ortho-Phosphate-P units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 1

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.002	0.000	0.002	0.002	1
05/15/90	176	0.002	0.000	0.002	0.002	2
07/10/90	232					0
03/27/91	492					0
OVERALL		0.002	0.000	0.002	0.002	3
C.V.		0%				

PARAMETER: Ortho-Phosphate-P units: mg/L
AVERAGE CONCENTRATIONS
SAMPLE: GROUNDWATER - BASIN 2

DATE	DAY No.	AVG	STD	MIN	MAX	n
11/20/89	0					
03/27/90	127	0.002	0.000	0.002	0.002	1
05/15/90	176	0.002	0.000	0.002	0.002	2
07/10/90	232					0
03/27/91	492					0
OVERALL		0.002	0.000	0.002	0.002	3
C.V.		0%				

Appendix B-3

Soil Data and Discussion

SOIL:Total nitrogen units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	17667	2625	14.9%	14000	20000	3
20-30 cm	15950	6050	37.9%	9900	22000	2
60-70 cm	12500	500	4.0%	12000	13000	2
Overall	14983	4252	28.4%	9900	22000	7
BASIN 2						
0-10 cm	25333	1700	6.7%	23000	27000	3
20-30 cm	27300	2700	9.9%	24600	30000	2
60-70 cm	19000	6000	31.6%	13000	25000	2
Overall	24086	4961	20.6%	13000	30000	7
CONTROL						
0-10 cm	22500	1500	67.0%	21000	24000	2
20-30 cm	26000	0	0.0%	26000	26000	2
60-70 cm	20150	4850	24.1%	15300	25000	2
Overall	22883	3781	16.6%	15300	26000	6

LOCATION:			BASIN 1	
SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89				
02/06/90	78	20000		
05/15/90	176			
08/21/90	274	14000	9900	12000
03/27/91	492	19000	22000	13000

			BASIN 2	
		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	26000		
05/15/90	176			
08/21/90	274	27000	24600	13000
03/27/91	492	23000	30000	25000

			CONTROL	
		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78			
05/15/90	176			
08/21/90	274	24000	26000	15300
03/27/91	492	21000	26000	25000

SOIL:Total Phosphorus units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	1200	235	19.5%	1000	1600	1
20-30 cm	1133	47	4.2%	1100	1200	1
60-70 cm	883	162	18.4%	710	1100	1
Overall	1083	221	20.4%	710	1600	1
BASIN 2						
0-10 cm	1685	169	10.0%	1400	1840	1
20-30 cm	1500	82	5.4%	1400	1600	1
60-70 cm	1167	47	4.0%	1100	1200	1
Overall	1474	246	16.7%	1100	1840	1
CONTROL						
0-10 cm	1167	378	32.4%	870	1700	1
20-30 cm	1367	205	15.0%	1100	1600	1
60-70 cm	1167	94	8.1%	1100	1300	1
Overall	1233	271	22.0%	870	1700	1

LOCATION:			BASIN 1	
SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89				
02/06/90	78	1100		
05/15/90	176	1600	1100	710
08/21/90	274	1100	1200	1100
03/27/91	492	1000	1100	840

			BASIN 2	
		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	1760		
05/15/90	176	1840	1400	1200
08/21/90	274	1740	1500	1200
03/27/91	492	1400	1600	1100

			CONTROL	
		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78			
05/15/90	176	1700	1600	1100
08/21/90	274	930	1400	1300
03/27/91	492	870	1100	1100

SOIL: Aluminum units: ug/g (ICP)

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	6658	1961	29.5%	4760	9580	4
20-30 cm	7197	1513	21.0%	5290	8990	3
60-70 cm	11547	1952	16.9%	9040	13800	3
Overall	8142	2824	34.7%	4760	13800	10
BASIN 2						
0-10 cm	9238	893	9.7%	7760	9970	4
20-30 cm	10307	1631	15.8%	8220	12200	3
60-70 cm	14580	5069	34.8%	7440	18700	3
Overall	11161	3746	33.6%	7440	18700	10
CONTROL						
0-10 cm	8110	0	0.0%	8110	8110	1
20-30 cm	8260	0	0.0%	8260	8260	1
60-70 cm	7290	0	0.0%	7290	7290	1
Overall	7887	426	5.4%	7290	8260	3

SOIL: Aluminum units: ug/g
LOCATION: BASIN 1
SAMPLE #:

DATE	DAY No.	S1-1 0-10 cm	S1-2 30-40 cm	S1-3 60-70 cm
11/20/89				
02/06/90	78	9580	0	0
05/15/90	176	7310	8990	11800
08/21/90	274	4980	7310	13800
03/27/91	492	4760	5290	9040

BASIN 2

		S2-1 0-10 cm	S2-2 30-40 cm	S2-3 60-70 cm
02/06/90	78	9920	0	0
05/15/90	176	9970	12200	17600
08/21/90	274	9300	10500	18700
03/27/91	492	7760	8220	7440

CONTROL

		C-1 0-10 cm	C-2 30-40 cm	C-3 60-70 cm
02/06/90	78	0	0	0
05/15/90	176	0	0	0
08/21/90	274	0	0	0
03/27/91	492	8110	8260	7290

SOIL: Copper units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	17.6	4.6	26.3%	13.0	24.7	4
20-30 cm	17.3	2.1	12.3%	15.0	20.1	3
60-70 cm	19.4	3.9	19.9%	16.0	26.0	4
Overall	18.2	3.9	21.6%	13.0	26.0	11
BASIN 2						
0-10 cm	26.2	0.6	2.4%	25.4	26.9	3
20-30 cm	22.9	1.0	4.5%	21.5	23.9	3
60-70 cm	20.0	2.0	10.1%	17.7	22.6	3
Overall	23.0	2.9	12.5%	17.7	26.9	9
CONTROL						
0-10 cm	23.6	6.9	29.4%	15.0	32.0	3
20-30 cm	22.3	0.6	2.9%	21.4	22.9	3
60-70 cm	17.6	1.9	10.8%	15.0	19.5	3
Overall	21.2	4.9	23.2%	15.0	32.0	9

SOIL: COPPER units: ug/g
LOCATION: BASIN 1

SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89	0			
02/06/90	78	24.7	0	26
05/15/90	176	18.6	20.1	16
08/21/90	274	14	15	17.9
03/27/91	492	13	16.7	17.8

BASIN 2

		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	0	0	0
05/15/90	176	25.4	23.9	19.7
08/21/90	274	26.3	23.4	22.6
03/27/91	492	26.9	21.5	17.7

CONTROL

		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	0	0	0
05/15/90	176	25.4	23.9	19.7
08/21/90	274	26.3	23.4	22.6
03/27/91	492	26.9	21.5	17.7

SOIL: Iron units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	7257.5	1576.1	21.7%	5610.0	9850.0	4
20-30 cm	5590.0	3068.3	54.9%	3180.0	9920.0	3
60-70 cm	3170.0	1321.9	41.7%	1860.0	4980.0	3
Overall	5061.1	2684.7	53.2%	1860.0	9920.0	10
BASIN 2						
0-10 cm	12535.0	3034.6	24.2%	7640.0	15600.0	4
20-30 cm	8033.3	2643.3	32.9%	5570.0	11700.0	3
60-70 cm	4706.7	1735.2	36.9%	2980.0	7080.0	3
Overall	8836.0	4179.1	47.3%	2980.0	15600.0	10
CONTROL						
0-10 cm	13370.0	5628.4	42.1%	8810.0	21300.0	3
20-30 cm	8406.7	2827.6	33.6%	5670.0	12300.0	3
60-70 cm	4543.3	1763.7	38.8%	2390.0	6710.0	3
Overall	8773.3	5226.2	59.6%	2390.0	21300.0	9

SOIL: Iron units: ug/g

LOCATION: BASIN 1

SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89				
02/06/90	78	9850	0	0
05/15/90	176	6620	9920	4980
08/21/90	274	6950	3180	2670
03/27/91	492	5610	3670	1860

BASIN 2

		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	14400	0	0
05/15/90	176	12500	11700	7080
08/21/90	274	7640	5570	2980
03/27/91	492	15600	6830	4060

CONTROL

		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	0	0	0
05/15/90	176	10000	7250	4530
08/21/90	274	8810	5670	2390
03/27/91	492	21300	12300	6710

SOIL: Potassium units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	625.0	216.5	34.6%	500.0	1000.0	4
20-30 cm	433.3	94.3	21.8%	300.0	500.0	3
60-70 cm	300.0	0.0	0.0%	300.0	300.0	3
Overall	411.1	200.2	48.7%	300.0	1000.0	10
BASIN 2						
0-10 cm	550.0	269.3	49.0%	300.0	1000.0	4
20-30 cm	400.0	81.6	20.4%	300.0	500.0	3
60-70 cm	333.3	47.1	14.1%	300.0	400.0	3
Overall	440.0	201.0	45.7%	300.0	1000.0	10
CONTROL						
0-10 cm	500.0	81.6	16.3%	400.0	600.0	3
20-30 cm	333.3	47.1	14.1%	300.0	400.0	3
60-70 cm	300.0	0.0	0.0%	300.0	300.0	3
Overall	377.8	103.0	27.3%	300.0	600.0	9

SOIL: Potassium units: ug/g

LOCATION:			BASIN 1	
SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89				
02/06/90	78	1000	0	0
05/15/90	176	500	500	300
08/21/90	274	500	500	300
03/27/91	492	500	300	300
			BASIN 2	
		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	1000	0	0
05/15/90	176	300	500	400
08/21/90	274	400	300	300
03/27/91	492	500	400	300
			CONTROL	
		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	0	0	0
05/15/90	176	600	300	300
08/21/90	274	500	400	300
03/27/91	492	400	300	300

SOIL: Manganese units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	240.8	122.2	50.8%	138.0	449.0	4
20-30 cm	465.7	519.2	111.5%	94.1	1200.0	3
60-70 cm	165.2	148.0	89.6%	43.9	413.0	4
Overall	239.9	318.8	132.9%	43.9	1200.0	11
BASIN 2						
0-10 cm	289.7	183.2	63.2%	89.1	532.0	3
20-30 cm	195.7	50.3	25.7%	132.0	255.0	3
60-70 cm	137.6	90.5	65.8%	52.5	263.0	3
Overall	207.7	136.7	65.8%	52.5	532.0	9
CONTROL						
0-10 cm	1956.3	1774.8	90.7%	309.0	4420.0	3
20-30 cm	929.0	655.3	70.5%	379.0	1850.0	3
60-70 cm	378.7	250.2	66.1%	102.0	708.0	3
Overall	1088.0	1281.2	117.8%	102.0	4420.0	9

LOCATION: BASIN 1

SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89	0			
02/06/90	78	449.0		413.0
05/15/90	176	176.0	1200.0	144.0
08/21/90	274	200.0	103.0	60.0
03/27/91	492	138.0	94.1	43.9

BASIN 2

		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89	0			
02/06/90	78			
05/15/90	176	89.1	255.0	263.0
08/21/90	274	248.0	132.0	52.5
03/27/91	492	532.0	200.0	97.4

CONTROL

		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89	0			
02/06/90	78			
05/15/90	176	309	379	326
08/21/90	274	1140	558	102
03/27/91	492	4420	1850	708

SOIL: Zinc units: ug/g

BASIN 1	AVG	STD	C.V.	MIN	MAX	n
0-10 cm	64.5	31.1	48.1%	24.2	111.0	4
20-30 cm	100.5	88.9	88.5%	23.2	225.0	3
60-70 cm	58.0	51.6	88.9%	20.3	131.0	3
Overall	78.8	62.3	79.0%	20.3	225.0	10
BASIN 2						
0-10 cm	76.1	53.4	70.2%	18.8	163.0	4
20-30 cm	75.5	30.8	40.8%	35.3	110.0	3
60-70 cm	54.2	1.2	2.3%	53.0	55.9	3
Overall	69.4	39.0	56.3%	18.8	163.0	10
CONTROL						
0-10 cm	123.3	33.5	27.2%	76.0	149.0	3
20-30 cm	80.7	36.3	45.0%	39.8	128.0	3
60-70 cm	46.7	25.3	54.2%	11.0	67.2	3
Overall	83.6	44.8	53.7%	11.0	149.0	9

SOIL: Zinc units: ug/g

LOCATION: BASIN 1

SAMPLE #:		S1-1	S1-2	S1-3
		0-10 cm	30-40 cm	60-70 cm
DATE	DAY No.			
11/20/89				
02/06/90	78	24.2		
05/15/90	176	66.7	225	131
08/21/90	274	111	53.2	22.8
03/27/91	492	56.2	23.2	20.3

BASIN 2

		S2-1	S2-2	S2-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78	52.9		
05/15/90	176	163	110	55.9
08/21/90	274	18.8	81.1	53
03/27/91	492	69.7	35.3	53.8

CONTROL

		C-1	C-2	C-3
		0-10 cm	30-40 cm	60-70 cm
02/06/90	78			
05/15/90	176	145	74.3	67.2
08/21/90	274	76	39.8	11
03/27/91	492	149	128	61.8

Appendix B-3

Soil Data and Discussion

1. SOIL ALUMINUM

Comparison Between Sites

Soil Al content at the three depths within the two experimental basins and at the control site are shown in Figure B-3-1. Average Al content was highest in Basin 2 (11,161 ug/g), followed by Basin 1 (8,142 ug/g) and the Control (7,887 ug/g). Within the experimental wetland, there was a trend of increasing Al content with depth; differences between the 0 to 10 cm and 30 to 40 cm strata were generally small compared to those between the latter and 60 to 70 cm depth. At the control site, Al content at the surface and 30 to 40 cm depths was similar, and only sightly lower at 60 to 70 cm.

Seasonal Changes

Seasonal changes in soil Al are shown in Figure B-3-2. At surface, values in Basins 1 and 2 tended to decrease over time; although both basins had similar levels in February 1990, a greater decrease occurred in Basin 1 than in Basin 2. Seasonal Al data for the control site are not available.

At 30 to 40 cm, Al content in both basins followed a similar decreasing trend, although the level in Basin 2 was initially higher.

At 60 to 70 cm, Al content increased in both basins between May and August 1990 and by March 1991 had decreased to lower levels than encountered the previous spring.

Comparison Between Years

Average soil Al content in the experimental wetland during Year 3 was approximately 7,800 ug/g, compared to 7,900 ug/g at the control site. These values are lower than the 10,200 ug/g reported for Year 2 (Norecol 1990). Soil Al content was not measured at the beginning of Year 1. The decrease in soil Al between Year 2 and Year 3 may reflect dilution by the increased hydraulic loading of the experimental site.

Further analysis and statistical interpretation of the soil Al data are recommended.

COMPARISON OF SOIL ALUMINUM CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

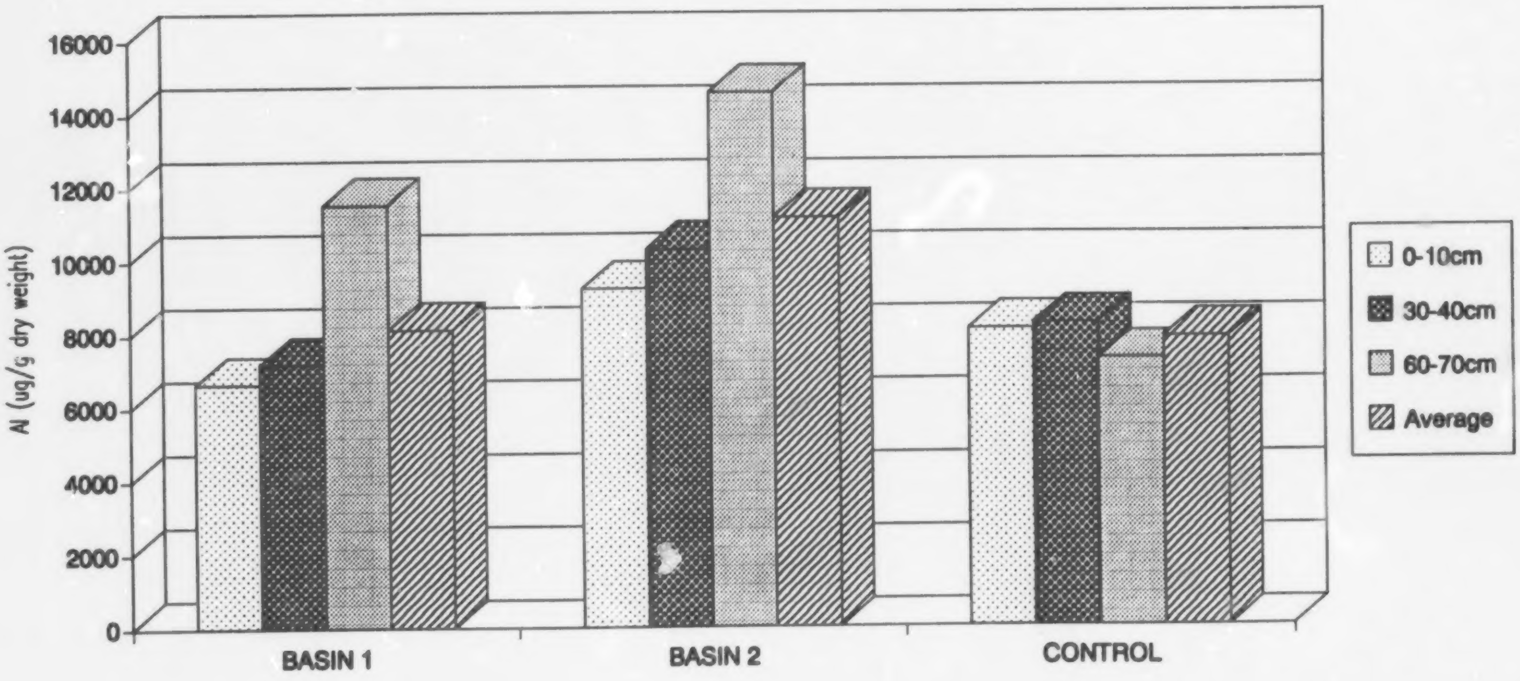


Figure B-3-1

SEASONAL CHANGES IN SOIL ALUMINUM CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

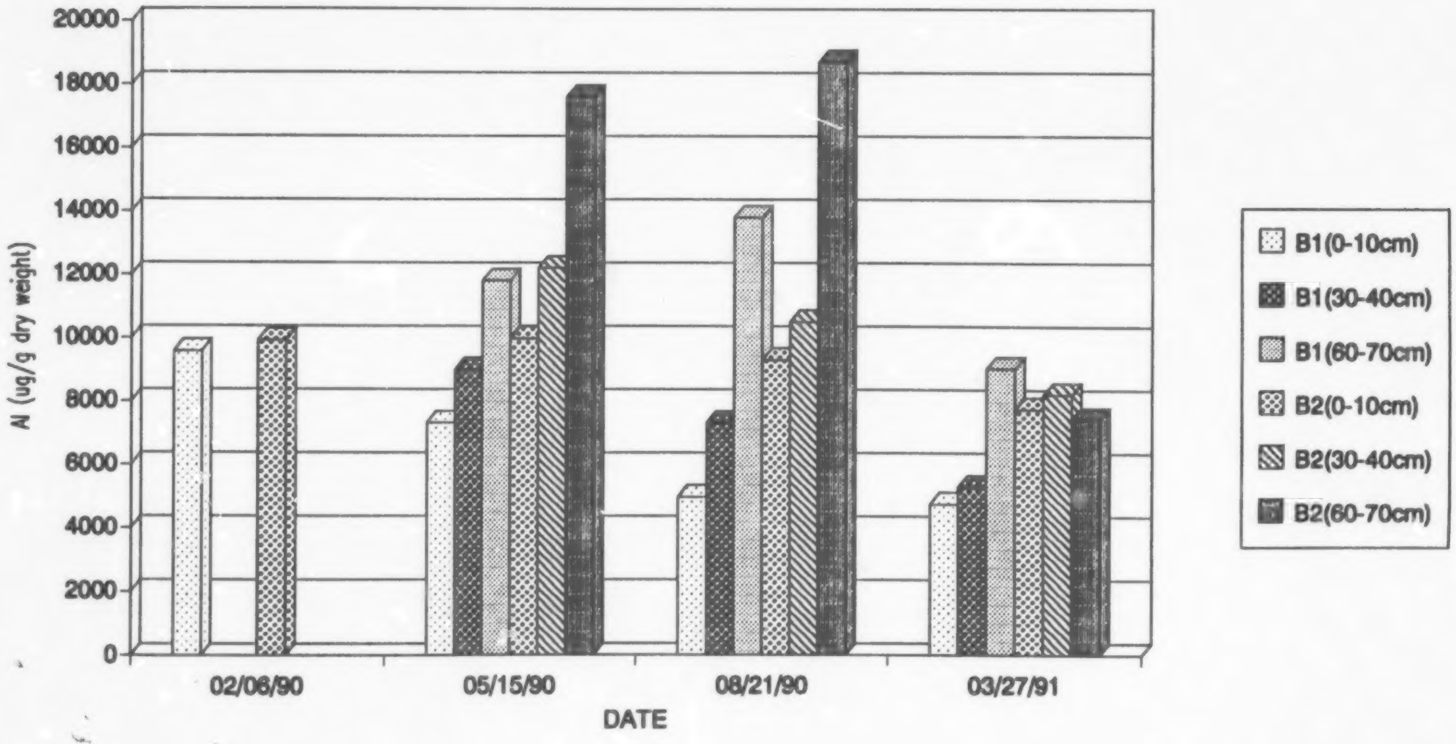


Figure B-3-2

2. SOIL COPPER

Comparison Between Sites

Soil Cu content in the experimental basins and the control site are shown in Figure B-3-3. Average Cu content was highest in Basin 2 (23 ug/g), followed by the Control (21.2 ug/g) and Basin 1 (18.2 ug/g). Basin 2 and the control showed a trend of decreasing Cu content with depth whereas, in Basin 1, the highest levels occurred at 60 to 70 cm and there was little difference in Cu content between the surface and 30 to 40 cm strata. These results suggest high natural variability between sites.

Seasonal Changes

Seasonal changes in soil Cu content between depths and sites are summarized in Figure B-3-4. At surface, changes in Cu content in the two basins were dissimilar. In Basin 1 there was a trend of decreasing Cu content between winter and summer 1990 and a further slight decrease by late winter 1991. In Basin 2, there was a slight decrease between winter and spring 1990, followed by a slight increase through the remainder of the monitoring period. The reasons for the difference between basins is unknown, and may be due to natural variability. In the Control site, there was a slight increase throughout the monitoring period.

At 30 to 40 cm depth, there was a decrease in Cu content in Basin 1 between spring and summer 1990, followed by a slight increase by late winter 1991. In Basin 2 over the same sampling periods, there was a slight decrease in summer, followed by a larger decrease by late winter 1991. In the Control, there was a slight decrease between spring and summer, followed by a slightly larger decrease by the end of winter 1991.

At 60 to 70 cm depth, there was in both basins a similar trend of increasing Cu between spring and summer 1990. By late winter 1991, Cu in Basin 1 remained unchanged, whereas in Basin 2 had decreased to a similar level as in Basin 1. In the Control, Cu followed a similar trend as that in Basin 2.

Comparison Between Years

Average surface Cu during Year 3 was 21.4 ug/g in the experimental wetland and 23.6 ug/g in the Control. These values are higher than the average of 15.9 ug/g in the experimental wetland during Year 2 (Norecol 1990). Surface Cu content measured at the beginning of Year 1 averaged 28.1 ug/g.

Further analysis and statistical interpretation of the soil Cu data are recommended.

COMPARISON OF SOIL COPPER CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

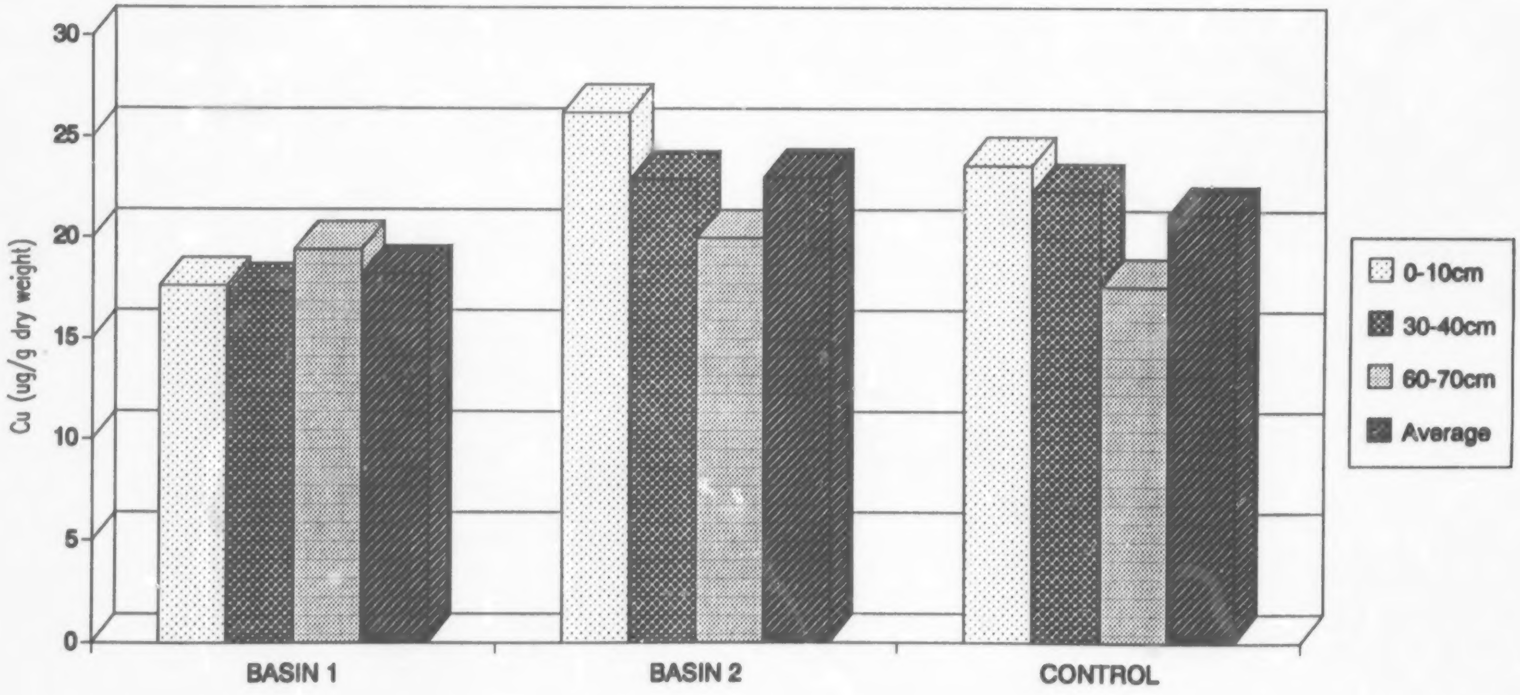


Figure B-3-3

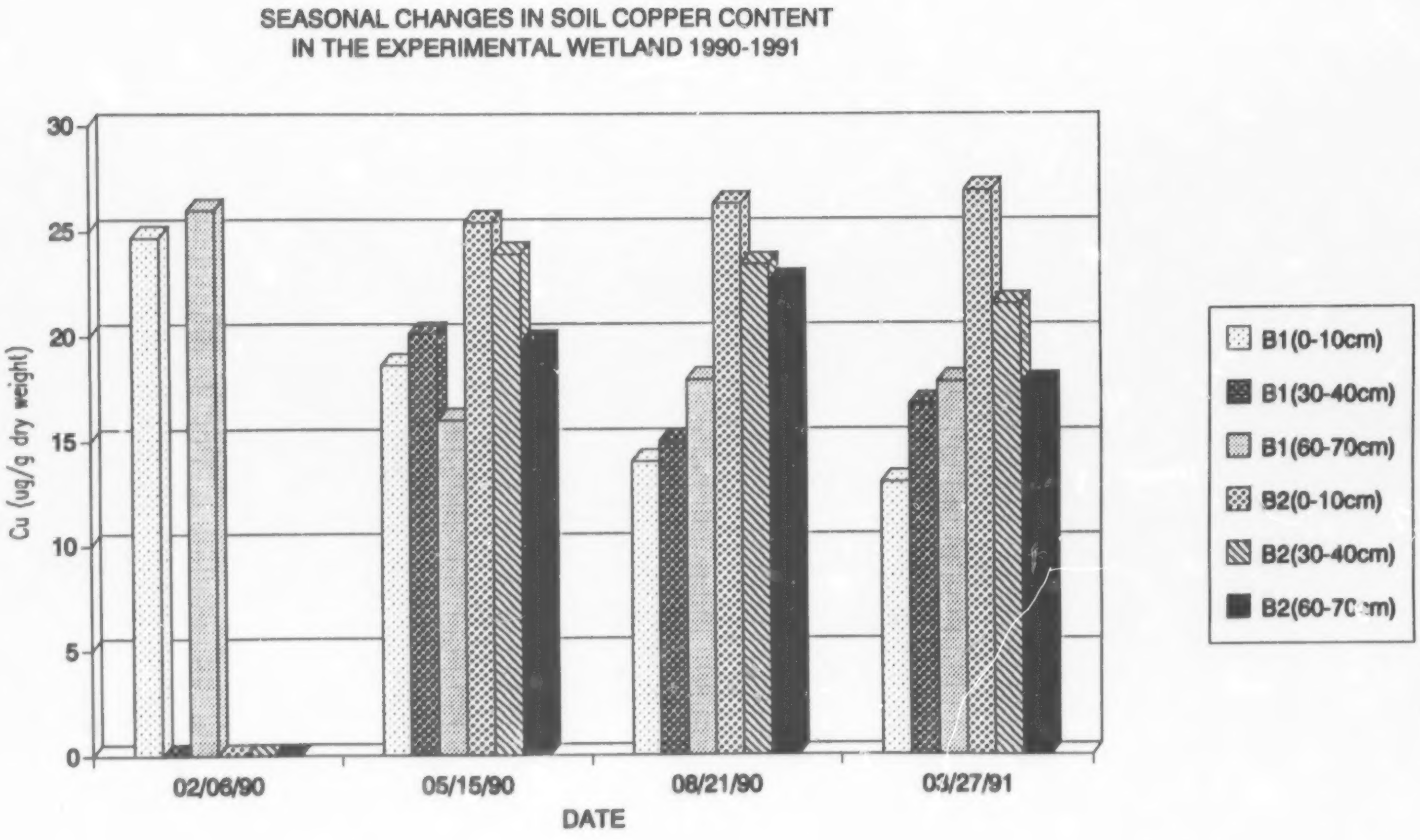

SEASONAL CHANGES IN SOIL COPPER CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991
Cu (ug/g dry weight)
30
25
20
15
10
5
0
02/06/90
05/15/90
08/21/90
03/27/91
DATE
B1(0-10cm)
B1(30-40cm)
B1(60-70cm)
B2(0-10cm)
B2(30-40cm)
B2(60-70cm)

Figure B-3-4

3. SOIL IRON

Comparison Between Sites

Figure B-3-5 summarizes the soil Fe content in the two experimental basins and the control site. Average Fe content was highest and similar in Basin 2 and the Control (8,836 and 8,773 ug/g, respectively), and lowest in Basin 1 (5,051 ug/g). There was a trend of decreasing Fe content with depth at all three locations. Presumably, the decreasing Fe content with depth reflects the decrease in biological activity, since presence of Fe is generally correlated with the biologically active strata (Mitsch and Gosselink 1986).

Seasonal Changes

Seasonal changes in soil Fe are shown in Figure B-3-6. At surface in late winter 1990, Fe in Basin 2 was almost 50% higher that in Basin 1 and, by spring 1990, Fe levels in both basins had decreased. During the ensuing summer, Fe in Basin 1 increased slightly whereas, in Basin 2, decreased further. Between summer 1990 and late winter 1991, Fe in Basin 1 decreased slightly, whereas in Basin 2 increased sharply. Surface Fe at the Control site followed a similar trend to Basin 2, with a much sharper increase between summer 1990 and late winter 1991.

Comparison Between Years

Average surface Fe content during Year 3 was 9,896 ug/g in the experimental wetland and 13,370 ug/g in the control. These values are higher than the 6,190 ug/g average measured during Year 2 (Norecol 1990) and higher than background surface soil Fe of 4,040 ug/g at the beginning of Year 1 (Norecol 1989). The data show that there has been a substantial net increase in soil Fe since the experiment was begun.

Further analysis and statistical interpretation of the soil Fe data are recommended.

4. SOIL POTASSIUM

Comparison Between Sites

Figure B-3-7 shows the soil potassium content in the two wetland basins and the control site during Year 3. Average K content was highest and similar in Basins 2 and 1 (440 and 411 ug/g, respectively), followed by the Control (378 ug/g). This trend probably reflects the contribution of K from the KNO_3 dosing solution and the increasing distance from the dosing point. There was a trend of decreasing K content with depth at all three locations, probably reflecting the surface and near-surface flow of high K water.

COMPARISON OF SOIL IRON CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

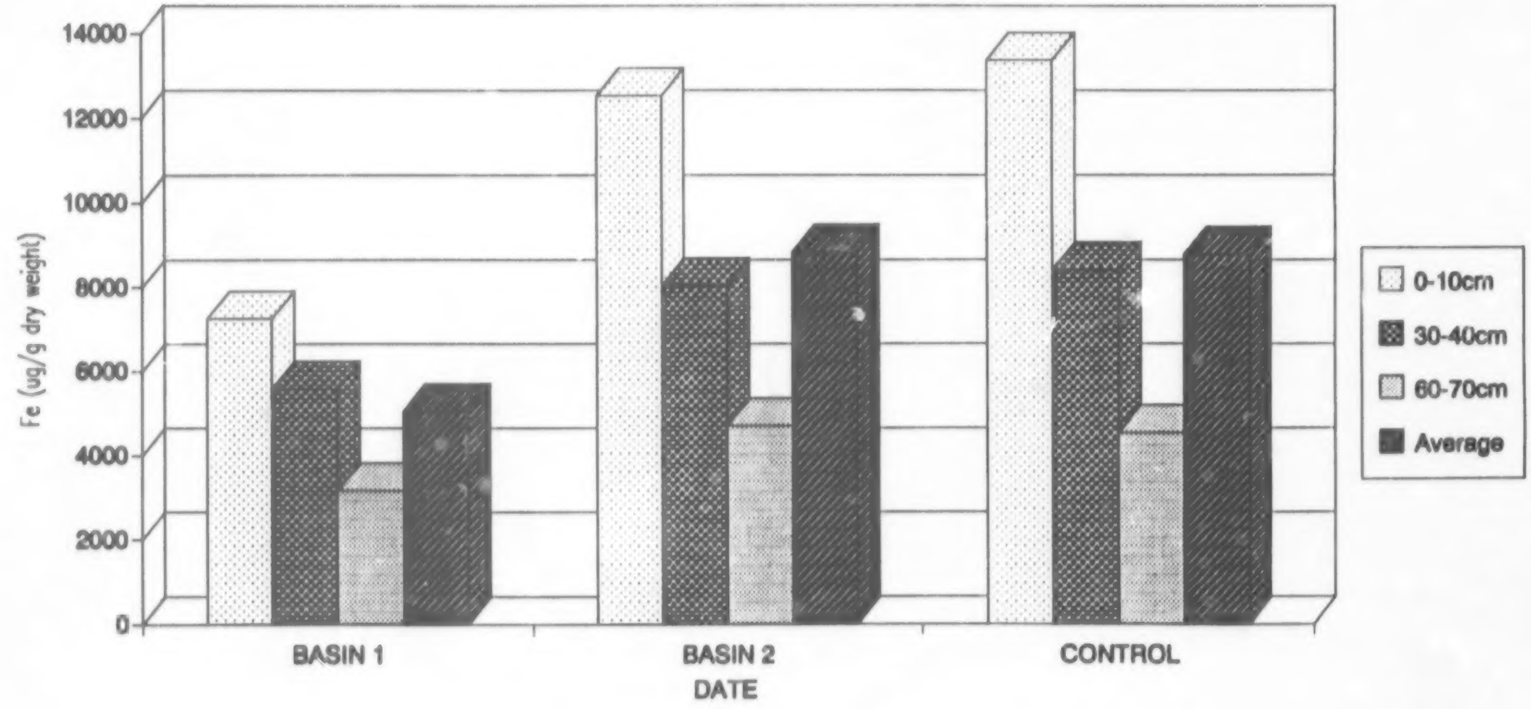
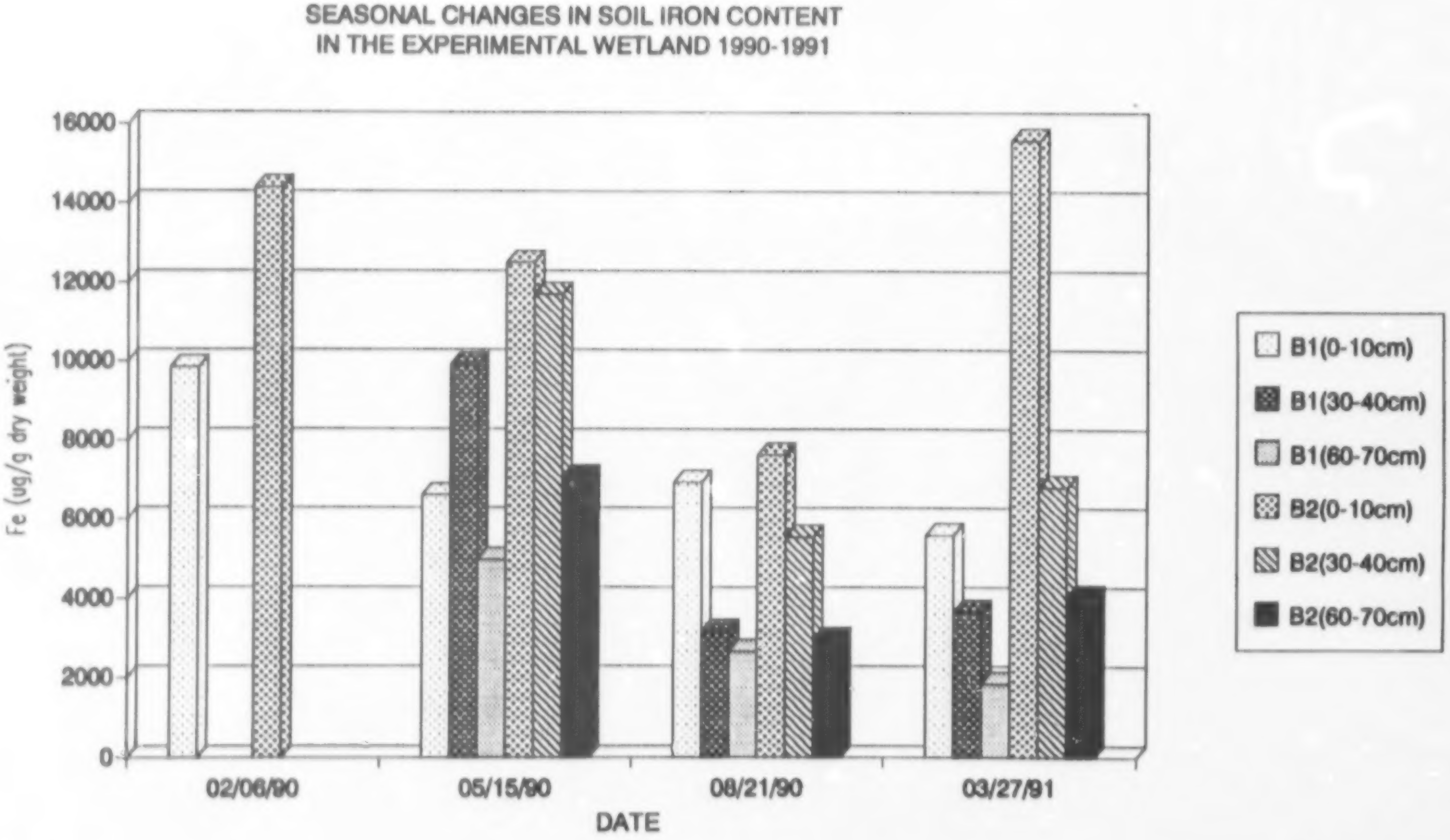


Figure B-3-5



SEASONAL CHANGES IN SOIL IRON CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

Figure B-3-6

COMPARISON OF SOIL POTASSIUM CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

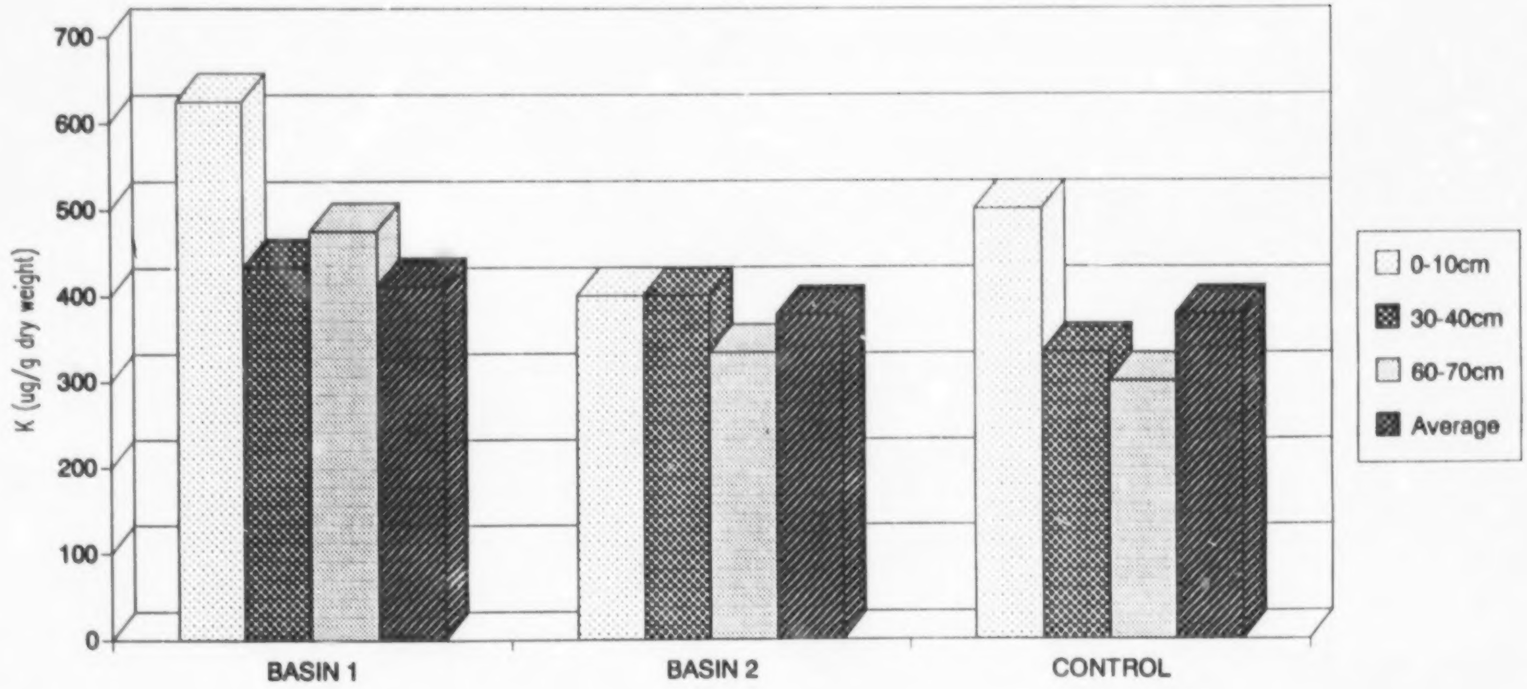


Figure B-3-7

Seasonal Changes

Figure B-3-8 shows the seasonal changes in soil K content during Year 3. Surface K content in Basin 1 and 2 was highest in late winter 1990. During the remainder of the monitoring period, K content in Basin 1 remained unchanged while that in Basin 2 increased slightly, although levels remained similar to those in Basin 1. In the control site, surface K tended to decrease slightly between spring 1990 and late winter 1991, although levels were similar to those in the experimental wetland. The high initial values in February 1990 probably reflect the high KNO_3 dosing concentration (up to 100 mgN/L) that was being applied during Year 2; soil K levels during the remainder of Year 3 diminished with the reduction of dosing concentration.

Comparison Between Years

Average surface soil K content during Year 3 was approximately 513 ug/g in the experimental wetland and 500 ug/g in the Control. These levels are similar to the 500 ug/g measured in Year 2 (Norecol 1990) and higher than the 118 ug/g background level measured at the beginning of Year 1 (Norecol 1989). The increase in soil K content reflects the K contributed to the site by the KNO_3 dosing solution.

Further analysis and statistical interpretation of the soil K data are recommended.

5. SOIL MANGANESE

Comparison Between Sites

Figure B-3-9 summarizes the soil Mn content in the experimental wetland and the control site during Year 3. Average Mn concentrations were highest at the control site (1088 ug/g) and were similar in Basins 1 and 2 (240 and 228 ug/g, respectively). Basin 2 and the Control showed a trend of decreasing Mn content with increasing depth. In Basin 1, Mn was highest at 30 to 40 cm, although Mn at surface was higher than at 60 to 70 cm.

Seasonal Changes

Seasonal changes in soil Mn during Year 3 are shown in Figure B-3-10. At surface, Mn content in both basins was similar in late winter 1990 and decreased by spring; during the remainder of the monitoring period, Mn in Basin 1 remained nearly constant between 140 and 180 ug/g, whereas in Basin 2 Mn increased steadily to 532 ug/g by late winter 1991. Surface Mn in the control increased from 309 ug/g in spring 1990 to 1140 ug/g in summer and 4420 ug/g by late winter 1991.

At 30 to 40 cm, Mn content in Basin 1 decreased slightly from 120 to 94 ug/g between spring 1990 and late winter 1991, while Mn in Basin 2 decreased between the spring and summer 1990 sampling dates and subsequently increased to 200 ug/g by late winter 1991. In the control, Mn at this depth in spring 1990 was slightly lower than in the experimental basins, increased slightly to 558 ug/g by summer 1990 and further increased sharply to 1850 ug/g by late winter 1991.

SEASONAL CHANGES IN SOIL POTASSIUM CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

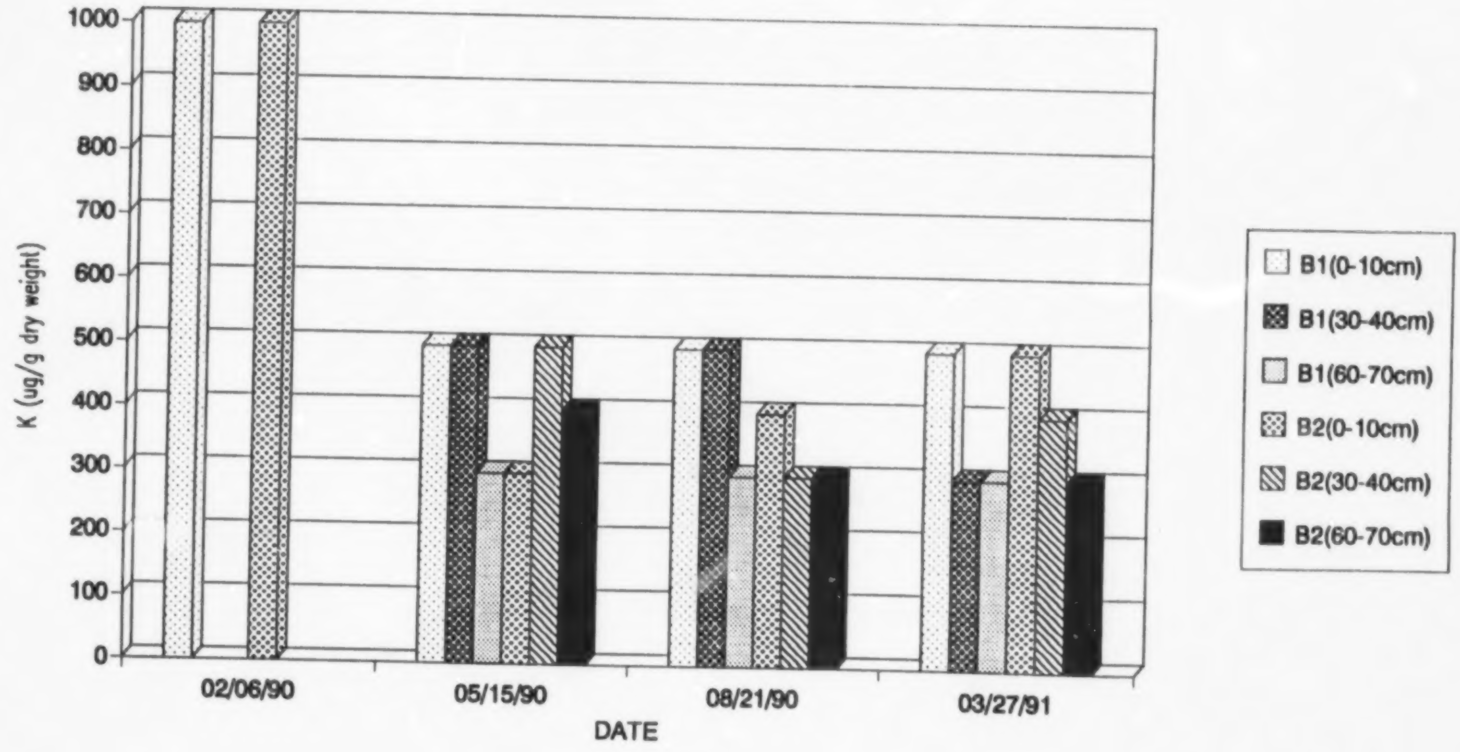


Figure B-3-8

COMPARISON OF SOIL MANGANESE CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

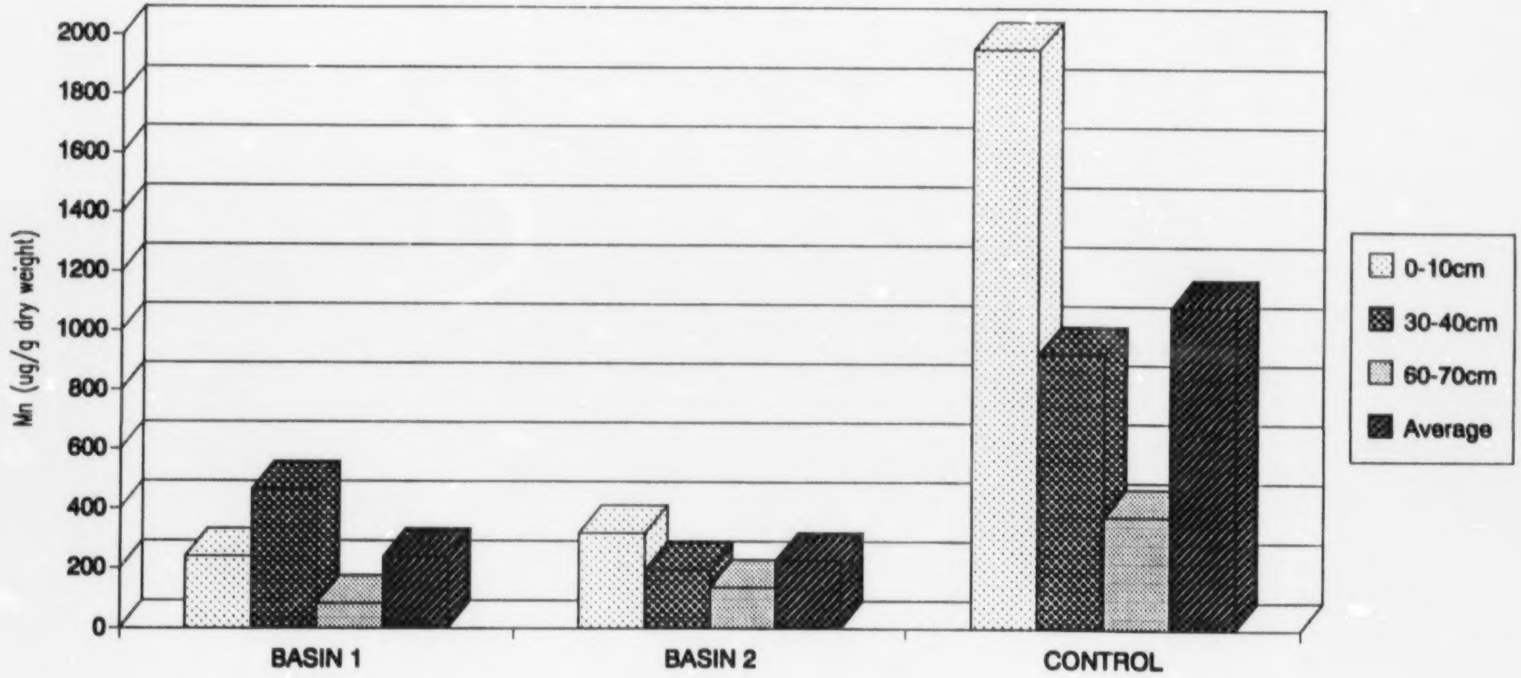


Figure B-3-9

SEASONAL CHANGES IN SOIL MANGANESE CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

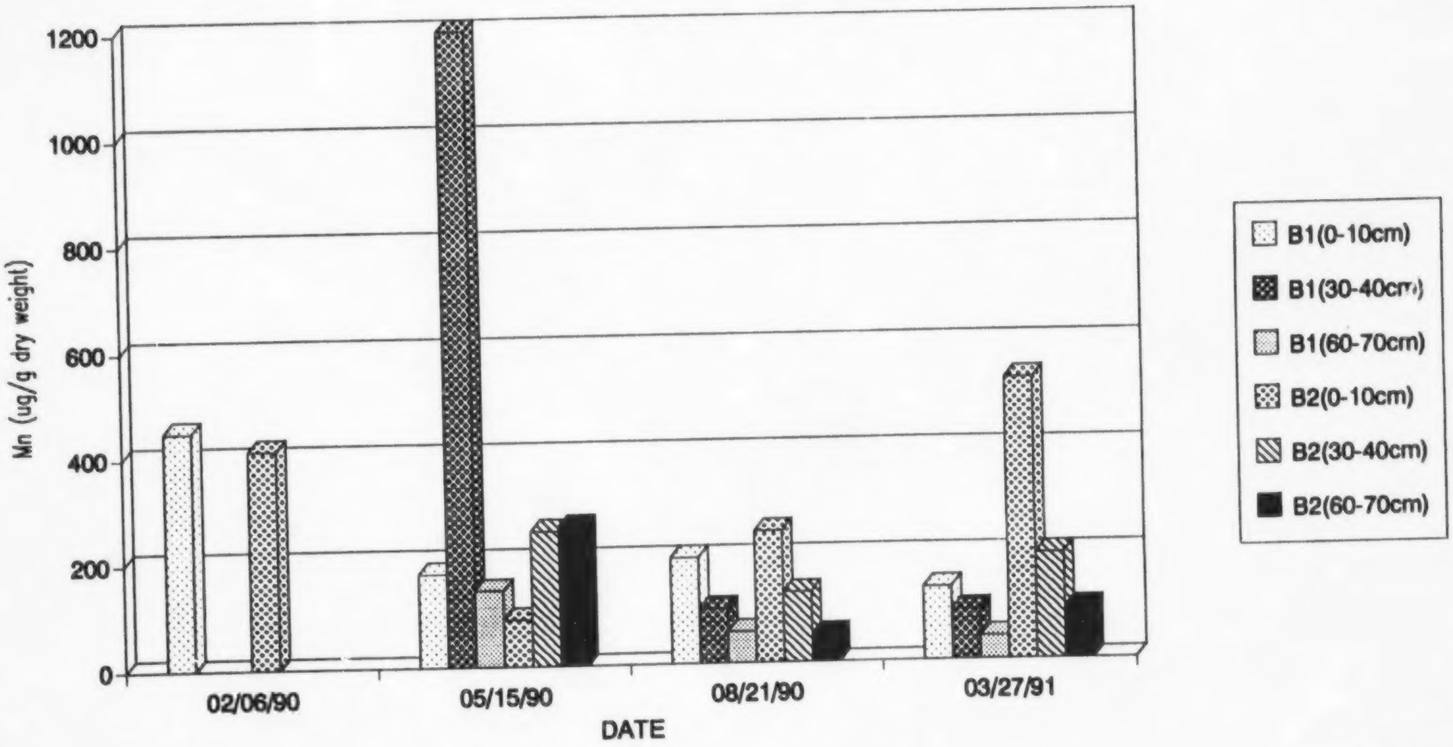


Figure B-3-10

At 60 to 70 cm, soil Mn content in Basin 1 decreased gradually from 144 ug/g in spring 1990 to 60 ug/g in summer and 50 ug/g by late winter 1991. In Basin 2, Mn at this depth decreased from 263 ug/g in spring 1990 to 53 ug/g in summer and subsequently increased to 97 ug/g by late winter 1991. A similar pattern, although with higher Mn concentrations, occurred in the Control: Mn at this site decreased from 326 ug/g in spring 1990 to 102 ug/g in summer and subsequently increased to 708 ug/g by late winter 1991.

Comparison Between Years

Average surface soil Mn during Year 3 was 280 ug/g in the experimental wetland and 1956 in the Control. These values are higher than the 128 ug/g average surface Mn measured as the baseline concentration at the beginning of Year 1. (Mn data were not obtained during Year 2.) The data show that there was a substantial increase in soil Mn content over the course of the experimental program, especially at the control site.

Further analysis and statistical interpretation of the soil Mn data are recommended.

6. SOIL ZINC

Comparison Between Sites

Figure B-3-11 summarizes the soil Zn content in the experimental wetland and the control site during Year 3. Average Zn content was highest in the control (84 ug/g), followed by Basin 1 (79 ug/g) and Basin 2 (69 ug/g). There was no consistent trend relating soil Zn content with depth. In Basin 1, the highest Zn content occurred at 30 to 40 cm, followed by the surface and 60 to 70 cm stata, with little difference between the latter two depths. In Basin 2, Zn content was almost identical in the surface and 30 to 40 cm stata, followed by lowest concentrations at 60 to 70 cm. The least variability between sites occurred in the samples from 60 to 70 cm depth.

Seasonal Changes

Seasonal changes in soil Zn are shown in Figure B-3-12. At surface, Zn content in Basin 1 increased from approximately 24 ug/g in winter 1990 to a peak of 111 ug/g by summer 1990, and decreased thereafter to 56 ug/g by late winter 1991. In Basin 2, soil Zn in this stratum increased from 53 ug/g in late winter 1990 to a peak of 163 ug/g in spring 1990, decreased to 19 ug/g by late summer and increased again to 56 ug/g by late winter 1991. In the control, Zn decreased from 145 ug/g in spring 1990 to 76 ug/g in summer, and increased subsequently to 149 ug/g in late winter 1990.

At 30 to 40 cm, soil Zn decreased sharply in Basin 1 between spring and summer 1990, decreasing more gradually during thereafter. In Basin 2 a similar trend occurred, although the decrease during spring and summer was less pronounced than in Basin 1. In the Control, Zn content decreased between spring and summer 1990, followed by a sharp increase between summer 1990 and late winter 1991.

COMPARISON OF SOIL ZINC CONTENT IN THE EXPERIMENTAL WETLAND AND CONTROL SITE
1990-1991

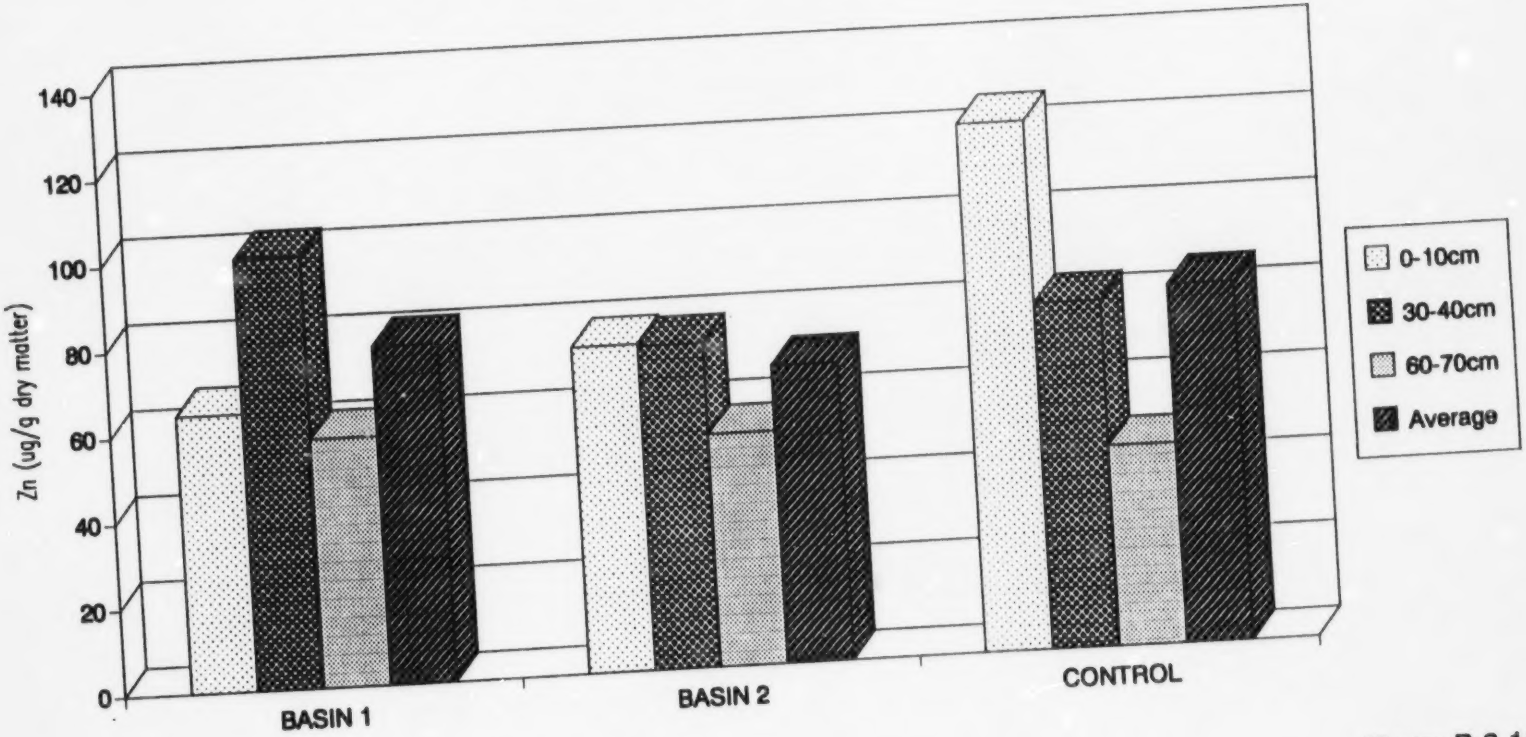


Figure B-3-11

SEASONAL CHANGES IN SOIL ZINC CONTENT
IN THE EXPERIMENTAL WETLAND 1990-1991

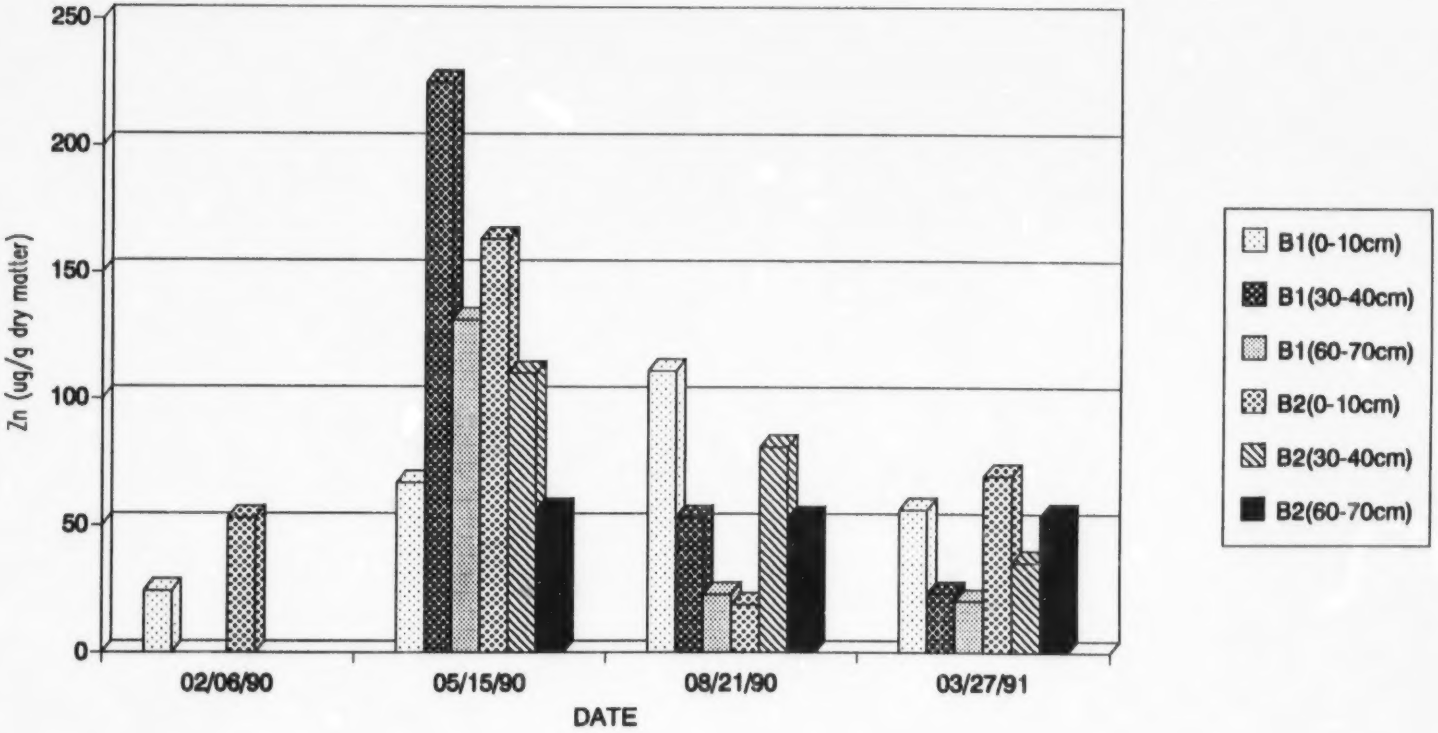


Figure B-3-12

At 60 to 70 cm, there was a marked decrease in Zn in Basin 1 between spring 1990 and summer 1990, followed by a very slight further decrease by late winter 1990. In Basin 2, the difference in Zn content over time was negligible. In the control, Zn content at this depth declined markedly between spring and summer 1990 and increased again by late winter 1991 to a similar level as in spring 1990.

Except for the surface layer in Basin 1, there appears to have been a consistent decrease in soil Zn at all depths between spring (May) and summer (August 1990). The reason for the increase in Basin 1 is uncertain, but may be related to Zn exports from the mine via drainage to the settling pond.

Comparison Between Years

Average surface soil Zn during Year 3 was 68 ug/g in the experimental wetland and 123 ug/g in the control. These values are substantially higher than the 20.6 ug/g measured in the experimental basins during Year 2 (Norecol 1990). Baseline surface soil Zn at measured at the beginning of Year 1 was 2.4 ug/g. The data show that there was a significant increase in soil Zn content over time. The causes of this increase are not known, but may include zinc exports originating from mining activities.

Further statistical analysis and interpretation of the soil Zn data are recommended.

Appendix B-4

Vegetation Data

PARAMETER: Total Nitrogen units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	30667	2494	28000	34000	3
05/15/90	300	32000	0	32000	32000	1
06/06/90	322	17333	943	16000	18000	3
07/10/90	356	12000	0	12000	12000	3
08/21/90	398	8150	1850	6300	10000	2
03/27/91	616	21000	4000	17000	25000	2
OVERALL	AVERAGE	19307	8598	6300	34000	12
	C.V.	44.5%				

PARAMETER: Total Nitrogen units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273	36000	1633	34000	38000	3
05/15/90	300	19000	0	19000	19000	1
06/06/90	322	24000	2944	20000	27000	3
07/10/90	356	8967	330	8600	9400	3
08/21/90	398	15500	500	15000	16000	2
03/27/91	616	8800	0	8800	8800	2
OVERALL	AVERAGE	19607	10373	8600	38000	14
	C.V.	52.9%				

PARAMETER: Total Nitrogen units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	4950	550	4400	5500	2
04/18/90	273	12000	0	12000	12000	3
05/15/90	300	7300	0	7300	7300	1
06/06/90	322	11333	471	11000	12000	3
07/10/90	356	12000	0	12000	12000	3
08/21/90	398	11300	1700	9600	13000	2
03/27/91	616	8900	1100	7800	10000	2
OVERALL	AVERAGE	10225	2526	4400	13000	16
	C.V.	0.2470406				

PARAMETER: Total Nitrogen units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	8150	450	7700	8600	2
04/18/90	273	23667	943	23000	25000	3
05/15/90	300	19000	0	19000	19000	1
06/06/90	322	12333	471	12000	13000	3
07/10/90	356	12667	471	12000	13000	3
08/21/90	398	8950	550	8400	9500	2
03/27/91	616	7100	900	6200	8000	2
OVERALL	AVERAGE	13338	5773	6200	25000	16
	C.V.	0.4328548				

PARAMETER: Total Nitrogen units:
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	6800	0	6800	6800	1
06/06/90	322					0
07/10/90	356					0
08/21/90	398	5700	0	5700	5700	1
03/27/91	616	11200	1800	9400	13000	2
OVERALL	AVERAGE	8725	2810	5700	13000	4
	C.V.	32.2%				

PARAMETER: Total Nitrogen units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	7300	0	7300	7300	1
04/18/90	273					0
05/15/90	300	22000	0	22000	22000	1
06/06/90	322					0
07/10/90	356					0
08/21/90	398	13000	0	13000	13000	1
03/27/91	616	6050	850	5200	6900	2
OVERALL	AVERAGE	14100	6051	7300	22000	3
	C.V.	42.9%				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	3433	45	3380	3490	3
05/15/90	300	1690	0	1690	1690	1
06/06/90	322	885	13	875	903	3
07/10/90	356	640	64	550	690	3
08/21/90	398	520	20	500	540	2
03/27/91	616	1765	615	1150	2380	2
OVERALL	AVERAGE	1510	1116	500	3490	12
	C.V.	73.9%				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273	6450	122	6300	6600	3
05/15/90	300	2770	0	2770	2770	1
06/06/90	322	1787	42	1730	1830	3
07/10/90	356	787	31	760	830	3
08/21/90	398	1002	29	973	1030	2
03/27/91	616	700	0	700	700	1
OVERALL	AVERAGE	2365	2212	560	6600	14
	C.V.	0.9355355				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	460	60	400	520	2
04/18/90	273	620	67	550	710	3
05/15/90	300	640	0	640	640	1
06/06/90	322	763	19	750	790	3
07/10/90	356	630	85	510	700	3
08/21/90	398	925	245	680	1170	2
03/27/91	616	470	100	370	570	2
OVERALL	AVERAGE	649	179	370	1170	16
	C.V.	27.6%				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	590	140	450	730	2
04/18/90	273	2703	62	2620	2770	3
05/15/90	300	1750	0	1750	1750	1
06/06/90	322	974	34	928	1010	3
07/10/90	356	812	17	800	837	3
08/21/90	398	675	45	630	720	2
03/27/91	616	525	105	420	630	2
OVERALL	AVERAGE	1175	789	420	2770	16
	C.V.	67.2%				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	590	0	590	590	1
06/06/90	322					0
07/10/90	356	440	28	420	480	3
08/21/90	398	420	0	420	420	1
03/27/91	616	360	20	340	380	2
OVERALL	AVERAGE	436	74	340	590	7
	C.V.	17.1%				

PARAMETER: Total Phosphorus units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	892	0	892	892	1
04/18/90	273					0
05/15/90	300	1740	0	1740	1740	1
06/06/90	322					0
07/10/90	356	697	46	650	760	3
08/21/90	398	420	0	420	420	1
03/27/91	616	325	105	220	430	2
OVERALL	AVERAGE	857	419	420	1740	6
	C.V.	48.9%				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0					
04/18/90	273.0	272	4	267	277	3
05/15/90	300.0	522	0	522	522	1
06/06/90	322.0	832	24	807	865	3
07/10/90	356.0	157	44	96	199	3
08/21/90	398.0	209	168	41	376	2
03/27/91	616.0	334	316	18	649	2
OVERALL	AVERAGE	385	286	18	865	12
	C.V.	74.2%				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273.0	36	1	34	37	3
05/15/90	300.0	6	0	6	6	1
06/06/90	322.0	12	0	11	12	3
07/10/90	356.0	10	1	9	11	3
08/21/90	398.0	36	0	36	36	2
03/27/91	616.0	34	9	25	43	2
OVERALL	AVERAGE	23	13	6	43	14
	C.V.	0.6				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	626	146	480	771	2
04/18/90	273.0	847	243	606	1180	3
05/15/90	300.0	749	0	749	749	1
06/06/90	322.0	925	24	903	958	3
07/10/90	356.0	631	148	425	767	3
08/21/90	398.0	272	41	231	313	2
03/27/91	616.0	359	21	338	379	2
OVERALL	AVERAGE	654	263	231	1180	16
	C.V.	0.4				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	101	56	45	157	2
04/18/90	273.0	45	2	42	47	3
05/15/90	300.0	21	0	21	21	1
06/06/90	322.0	54	2	52	57	3
07/10/90	356.0	56	4	51	60	3
08/21/90	398.0	98	29	69	127	2
03/27/91	616.0	94	7	87	101	2
OVERALL	AVERAGE	67	34	21	157	16
	C.V.	0.5				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0					0
04/18/90	273.0					0
05/15/90	300.0	973	0	973	973	1
06/06/90	322.0					0
07/10/90	356.0	58	7	51	68	3
08/21/90	398.0	328	0	328	328	1
03/27/91	616.0	163	0	163	163	1
OVERALL	AVERAGE	273	327	51	973	6
	C.V.	1.2				

PARAMETER: Aluminum units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	56	0	56	56	1
04/18/90	273.0					0
05/15/90	300.0	56	0	56	56	1
06/06/90	322.0					0
07/10/90	356.0	35	2	33	36	2
08/21/90	398.0	96	0	96	96	1
03/27/91	616.0	172	107	65	278	2
OVERALL	AVERAGE	55	22	33	96	5
	C.V.	0.4				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	4.5	1.2	3.6	6.1	3
05/15/90	300	4.2	0.0	4.2	4.2	1
06/06/90	322	6.7	0.3	6.5	7.1	3
07/10/90	356	4.2	0.4	3.6	4.6	3
08/21/90	398	2.8	1.4	1.4	4.2	2
03/27/91	616	4.9	0.1	4.8	4.9	2
OVERALL	AVERAGE	4.7	1.4	1.4	7.1	12
	C.V.	30.8%				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273	2.5	0.1	2.3	2.6	3
05/15/90	300	2.5	0.0	2.5	2.5	1
06/06/90	322	1.4	0.2	1.2	1.7	3
07/10/90	356	2.8	0.2	2.5	3.0	3
08/21/90	398	2.3	0.5	1.8	2.7	2
03/27/91	616	1.1	0.0	1.1	1.1	1
OVERALL	AVERAGE	2.1	0.6	1.1	3.0	14
	C.V.	29.3%				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	13.1	1.8	11.3	14.9	2
04/18/90	273	8.9	1.8	7.1	11.3	3
05/15/90	300	5.1	0.0	5.1	5.1	1
06/06/90	322	5.4	0.1	5.3	5.5	3
07/10/90	356	11.4	1.3	10.0	13.2	3
08/21/90	398	6.0	1.2	4.8	7.1	2
03/27/91	616	5.6	0.3	5.3	5.8	2
OVERALL	AVERAGE	8.2	3.2	4.8	14.9	16
	C.V.	38.7%				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	2.5	0.1	2.3	2.6	2
04/18/90	273	3.6	0.3	2.3	4.8	5
05/15/90	300	3.0	0.0	3.0	3.0	1
06/06/90	322	1.8	0.1	1.6	1.9	3
07/10/90	356	2.9	0.0	2.8	2.9	3
08/21/90	398	3.3	0.5	2.8	3.8	2
03/27/91	616	1.8	0.0	1.7	1.8	2
OVERALL	AVERAGE	2.8	1.0	1.6	4.8	16
	C.V.	34.3%				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	4.8	0.0	4.8	4.8	1
06/06/90	322					0
07/10/90	356	24.7	5.6	18.4	32.1	3
08/21/90	398	6.1	0.0	6.1	6.1	1
03/27/91	616	3.7	0.9	2.7	4.6	2
OVERALL	AVERAGE	13.2	10.7	2.7	32.1	7
	C.V.	81.0%				

PARAMETER: Copper units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	3.5	0.0	3.5	3.5	1
05/15/90	300	2.9	0.0	2.9	2.9	1
06/06/90	322					0
07/10/90	356	3.7	0.3	3.2	4.0	3
08/21/90	398	1.3	0.0	1.3	1.3	1
03/27/91	616	2.5	0.5	1.9	3.0	2
OVERALL	AVERAGE	3.1	0.9	1.3	4.0	6
	C.V.	28.5%				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0					
04/18/90	273.0	2283	9	2270	2290	3
05/15/90	300.0	1890	0	1890	1890	1
06/06/90	322.0	3697	92	3600	3820	3
07/10/90	356.0	3457	719	2440	3980	3
08/21/90	398.0	1430	170	1260	1600	2
03/27/91	616.0	8050	7950	100	16000	2
OVERALL	AVERAGE	3511	3637	100	3980	12
	C.V.	103.6%				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0			0	0	0
04/18/90	273.0	190	4	185	194	3
05/15/90	300.0	75	0	75	75	1
06/06/90	322.0	73	16	60	95	3
07/10/90	356.0	35	8	28	46	3
08/21/90	398.0	68	0	68	69	2
03/27/91	616.0	69	9	61	78	2
OVERALL	AVERAGE	89	55	28	194	14
	C.V.	0.6				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	7950	1690	6260	9640	2
04/18/90	273.0	5053	1117	3940	6580	3
05/15/90	300.0	4710	0	4710	4710	1
06/06/90	322.0	6860	179	6700	7110	3
07/10/90	356.0	2393	509	1690	2880	3
08/21/90	398.0	3485	1115	2370	4600	2
03/27/91	616.0	4835	2525	2310	7360	2
OVERALL	AVERAGE	5011	2215	1690	9640	16
	C.V.	0.4				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	217	85	132	301	2
04/18/90	273.0	237	7	228	243	3
05/15/90	300.0	105	0	105	105	1
06/06/90	322.0	340	4	335	344	3
07/10/90	356.0	135	7	128	144	3
08/21/90	398.0	516	186	330	701	2
03/27/91	616.0	225	78	147	303	2
OVERALL	AVERAGE	260	142	105	701	16
	C.V.	0.5				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0					0
04/18/90	273.0					0
05/15/90	300.0	10700	0	10700	10700	1
06/06/90	322.0					0
07/10/90	356.0	2900	257	2640	3250	3
08/21/90	398.0	35600	0	35600	35600	1
03/27/91	616.0	29400	0	29400	29400	1
OVERALL	AVERAGE	14067	13444	2640	35600	6
	C.V.	1.0				

PARAMETER: Iron units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0.0	89	0	89	89	1
04/18/90	273.0					0
05/15/90	300.0	144	0	144	144	1
06/06/90	322.0					0
07/10/90	356.0	83	3	79	86	2
08/21/90	398.0	200	0	200	200	1
03/27/91	616.0	4613	4387	226	9000	2
OVERALL	AVERAGE	120	46	79	200	5
	C.V.	0.4				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	384	2	382	387	3
05/15/90	300	199	0	199	199	1
06/06/90	322	578	9	570	590	3
07/10/90	356	147	14	127	158	3
08/21/90	398	138	47	92	185	2
03/27/91	616	581	519	61	1100	2
OVERALL	AVERAGE	355	273	61	590	12
	C.V.	77.1%				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0			0	0	0
04/18/90	273	789	10	781	803	3
05/15/90	300	314	0	314	314	1
06/06/90	322	228	13	210	241	3
07/10/90	356	191	9	183	203	3
08/21/90	398	599	30	569	628	2
03/27/91	616	1077	184	893	1260	2
OVERALL	AVERAGE	521	332	183	1260	14
	C.V.	63.7%				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	181	89	92	270	2
04/18/90	273	275	42	227	329	3
05/15/90	300	200	0	200	200	1
06/06/90	322	343	7	336	353	3
07/10/90	356	467	82	354	545	3
08/21/90	398	329	200	129	529	2
03/27/91	616	101	8	93	109	2
OVERALL	AVERAGE	292	144	92	545	16
	C.V.	49.2%				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	254	77	177	331	2
04/18/90	273	289	9	278	299	3
05/15/90	300	303	0	303	303	1
06/06/90	322	435	2	433	437	3
07/10/90	356	357	7	351	367	3
08/21/90	398	357	66	291	422	2
03/27/91	616	251	30	221	280	2
OVERALL	AVERAGE	329	75	177	437	16
	C.V.	22.7%				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	4600	0	4600	4600	1
06/06/90	322					0
07/10/90	356	779	67	711	871	3
08/21/90	398	8460	0	8460	8460	1
03/27/91	616	8410	0	8410	8410	1
OVERALL	AVERAGE	3968	3436	711	8460	6
	C.V.	86.6%				

PARAMETER: Manganese units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: HARDHACK-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	3454	0	3454	3454	1
04/18/90	273					0
05/15/90	300	520	0	520	520	1
06/06/90	322					0
07/10/90	356	416	14	402	430	2
08/21/90	398	381	0	381	381	1
03/27/91	616	766	314	452	1080	2
OVERALL	AVERAGE	1037	1209	381	3454	5
	C.V.	116.6%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					
04/18/90	273	23900.0	244.9	23600.0	24200.0	3
05/15/90	300	26900.0	0.0	26900.0	26900.0	1
06/06/90	322	18300.0	216.0	18100.0	18600.0	3
07/10/90	356	15233.3	419.0	14800.0	15800.0	3
08/21/90	398	12750.0	1550.0	11200.0	14300.0	2
03/27/91	616	32750.0	750.0	32000.0	33500.0	2
OVERALL	AVERAGE	20728.6	6544.7	11200.0	26900.0	12
	C.V.	31.6%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273	49700.0	941.6	48500.0	50800.0	3
05/15/90	300	58700.0	0.0	58700.0	58700.0	1
06/06/90	322	44000.0	707.1	43500.0	45000.0	3
07/10/90	356	19266.7	1228.4	18300.0	21000.0	3
08/21/90	398	26200.0	3000.0	23200.0	29200.0	2
03/27/91	616	2800.0	0.0	2800.0	2800.0	1
OVERALL	AVERAGE	32485.7	17757.2	2000.0	58700.0	14
	C.V.	54.7%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	6295.0	2695.0	3600.0	8990.0	2
04/18/90	273	9010.0	368.5	8490.0	9300.0	3
05/15/90	300	13200.0	0.0	13200.0	13200.0	1
06/06/90	322	10900.0	141.4	10700.0	11000.0	3
07/10/90	356	6933.3	942.8	5600.0	7600.0	3
08/21/90	398	12410.0	3990.0	8420.0	16400.0	2
03/27/91	616	5340.0	3240.0	2100.0	8580.0	2
OVERALL	AVERAGE	8863.8	3318.2	2100.0	16400.0	16
	C.V.	37.4%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

0	0	AVG	STD	MIN	MAX	n
07/19/89	0	14700.0	4500.0	10200.0	19200.0	2
04/18/90	273	23780.0	7947.7	10200.0	30300.0	5
05/15/90	300	27200.0	0.0	27200.0	27200.0	1
06/06/90	322	15033.3	492.2	14400.0	15600.0	3
07/10/90	356	13866.7	573.5	13200.0	14600.0	3
08/21/90	398	11150.0	2950.0	8200.0	14100.0	2
03/27/91	616	900.0	300.0	600.0	1200.0	2
OVERALL	AVERAGE	16056.3	8953.6	600.0	30300.0	16
	C.V.	55.8%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	3700.0	0.0	3700.0	3700.0	1
06/06/90	322					0
07/10/90	356	3133.3	634.2	2500.0	4000.0	3
08/21/90	398	4400.0	0.0	4400.0	4400.0	1
03/27/91	616	4850.0	850.0	4000.0	5700.0	2
OVERALL	AVERAGE	3885.7	964.3	2500.0	5700.0	7
	C.V.	24.8%				

PARAMETER: Potassium units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	12300.0	0.0	12300.0	12300.0	1
04/18/90	273					0
05/15/90	300	9620.0	0.0	9620.0	9620.0	1
06/06/90	322					0
07/10/90	356	6633.3	531.2	6000.0	7300.0	3
08/21/90	398	8480.0	0.0	8480.0	8480.0	1
03/27/91	616	1550.0	1050.0	500.0	2600.0	2
OVERALL	AVERAGE	8383.3	2117.9	6000.0	12300.0	6
	C.V.	25.3%				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-ROOT

DATE	DAY No.	STD	MIN	MAX	n
07/19/89	0				
04/18/90	273	0	37	38	3
05/15/90	300	0	52	52	1
06/06/90	322	0	24	25	3
07/10/90	356	5	21	32	3
08/21/90	398	24	6	54	2
03/27/91	616	8	25	40	2
OVERALL	AVERAGE	12	6	54	12
	C.V.				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: CATTAIL-SHOOT

DATE	DAY No.	STD	MIN	MAX	n
07/19/89	0				0
04/18/90	273	4	33	41	3
05/15/90	300	0	30	30	1
06/06/90	322	0	18	19	3
07/10/90	356	1	13	15	3
08/21/90	398	4	6	14	2
03/27/91	616	0	12	12	1
OVERALL	AVERAGE	10	6	41	14
	C.V.				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	26.3	1.3	25.0	27.5	2
04/18/90	273	30.3	3.0	26.6	33.9	3
05/15/90	300	46.8	0.0	46.8	46.8	1
06/06/90	322	42.7	0.5	42.2	43.4	3
07/10/90	356	38.0	4.1	32.3	41.2	3
08/21/90	398	39.4	20.5	18.9	59.8	2
03/27/91	616	39.7	8.0	31.7	47.6	2
OVERALL	AVERAGE	36.9	10.1	18.9	59.8	16
	C.V.	27.4%				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SEDGE-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	15.9	4.4	11.5	20.3	2
04/18/90	273	29.1	0.9	28.4	30.4	3
05/15/90	300	36.5	0.0	36.5	36.5	1
06/06/90	322	28.7	0.5	28.1	29.2	3
07/10/90	356	18.1	0.4	17.6	18.6	3
08/21/90	398	26.7	13.3	13.4	40.0	2
03/27/91	616	37.7	10.0	27.7	47.7	2
OVERALL	AVERAGE	26.6	9.4	11.5	47.7	16
	C.V.	35.5%				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: SWEETGALE-ROOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0					0
04/18/90	273					0
05/15/90	300	34.6	0.0	34.6	34.6	1
06/06/90	322					0
07/10/90	356	27.3	5.2	22.6	34.5	3
08/21/90	398	36.2	0.0	36.2	36.2	1
03/27/91	616	40.6	14.8	25.8	55.3	2
OVERALL	AVERAGE	33.4	10.3	22.6	55.3	7
	C.V.	30.7%				

PARAMETER: Zinc units: ug/g
AVERAGE CONCENTRATIONS
SAMPLE: HARDHACK-SHOOT

DATE	DAY No.	AVG	STD	MIN	MAX	n
07/19/89	0	41.5	0.0	41.5	41.5	1
04/18/90	273					0
05/15/90	300	45.6	0.0	45.6	45.6	1
06/06/90	322					0
07/10/90	356	24.9	1.7	22.7	26.9	3
08/21/90	398	16.4	0.0	16.4	16.4	1
03/27/91	616	16.2	0.0	16.2	16.2	1
OVERALL	AVERAGE	29.7	10.4	16.4	45.6	6
	C.V.	35.0%				

Appendix C

Colour Plates

PLATE 1: Quisam Wetland Project Site in late winter (March 14, 1990).

Foreground: toe of dam, settling pond outlet culvert, dosing station shed (note insulated dosing line from shed to water supply hose submerged in channel on right.

Center/Background: Experimental wetland with plywood baffles and plant height gauges.

Far Background: Natural wetland.

PLATE 2: Quisam Wetland Project Site in mid summer (July 8, 1990). Dense stands of transplanted cattail are visible in the experimental enclosure. Note also natural colonization by cattail in the drainage channel on center-right.

PLATE 3: Cattail (Typha latifolia) and sedge (Carex spp.) in the experimental wetland at Quisam Mine, (August 21, 1990). Vegetation height gauge is marked in 5cm intervals.

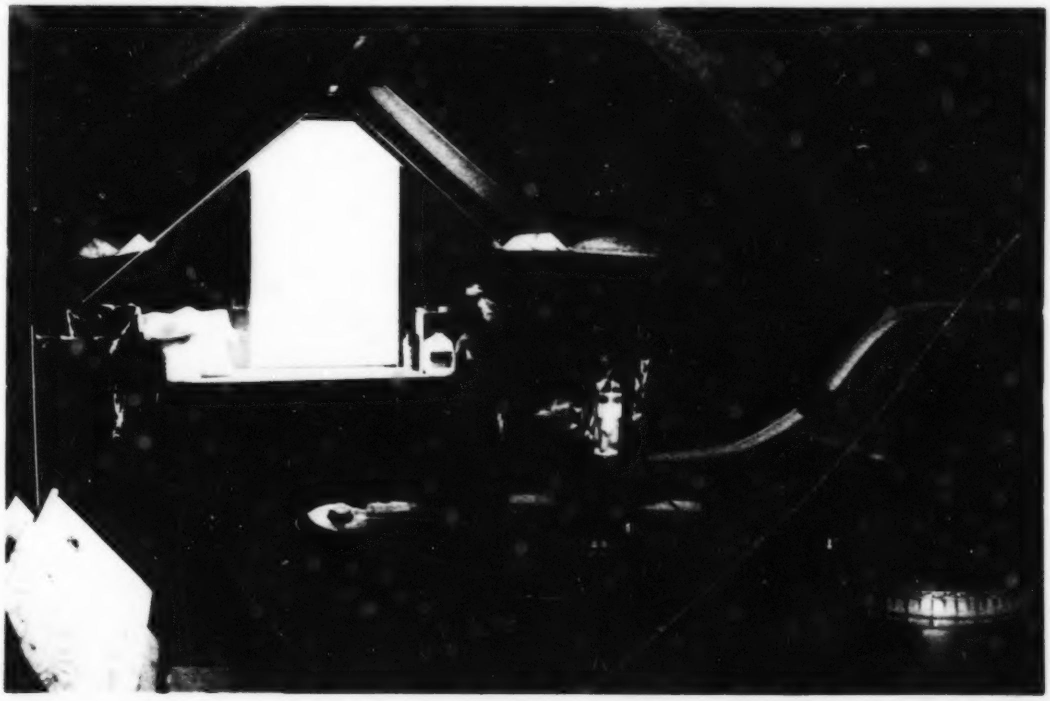


PLATE 4: Nitrate dosing station at the Quisam Wetland Project (March 27, 1990). Barrels contain concentrated KNO_3 solution which is pumped by a calibrated flow-metering pump (under plastic bag), through an insulated dosing tube (right) to the wetland water supply hose.